Recent Results from the TeVatron

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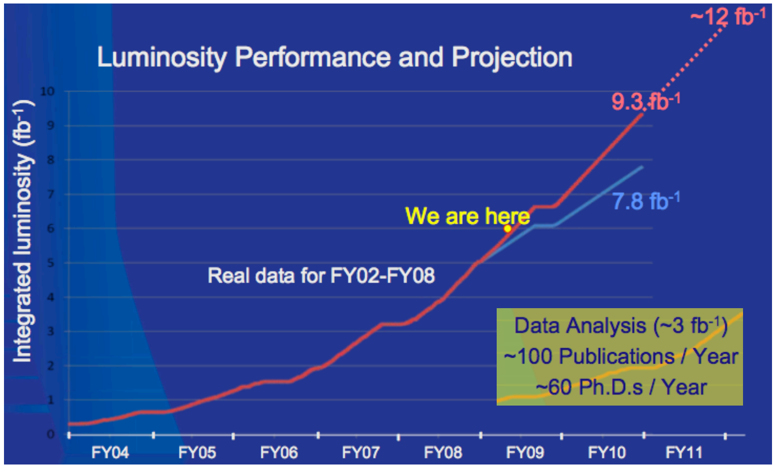
Introduction

- The TeVatron is currently the highest running energy collider in the world
  - ppbar collider, located about 30 miles west of Chicago, IL
    - 1.96 TeV in the C.M.
  - Data are accumulated at fast rate continuously
  - The machine and the detectors (CDF and D0) are performing very well
    - systematic uncertainties are very well under control

- Measurements are becoming very precise
  - Top quark mass known with precision < 2%
- New analyses are now looking for the needle in the hay stack
  - low cross section phenomena
  - The search for Higgs
  - Physics beyond the Standard Model



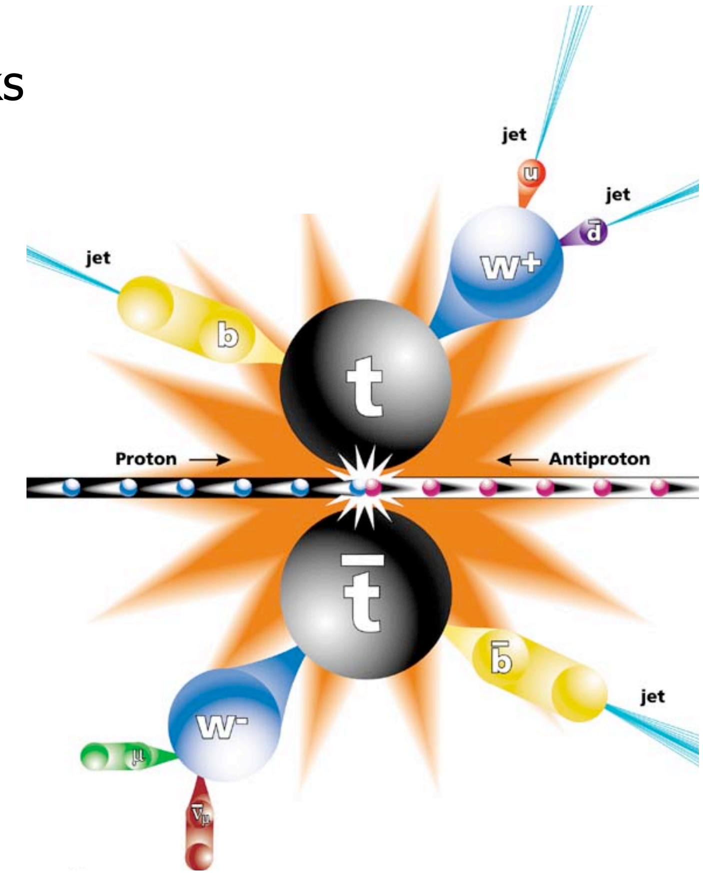
Tufts has been a member institution of the CDF collaboration since the early beginning (K.Sliwa, S.Rolli, B. Whitehouse, M. Hare, A.Napier)

Outline of the talk

- Collisions
- The Experimental apparatus
  - Machine
  - Detectors
- Observation of Single Top
  - Top physics and the TeVatron
  - EW single top production
  - A challenging analysis
  - Multivariate analyses techniques
- The search for the Higgs particle
  - Low mass Higgs vs High Mass Higgs
  - The importance of accumulating large statistics

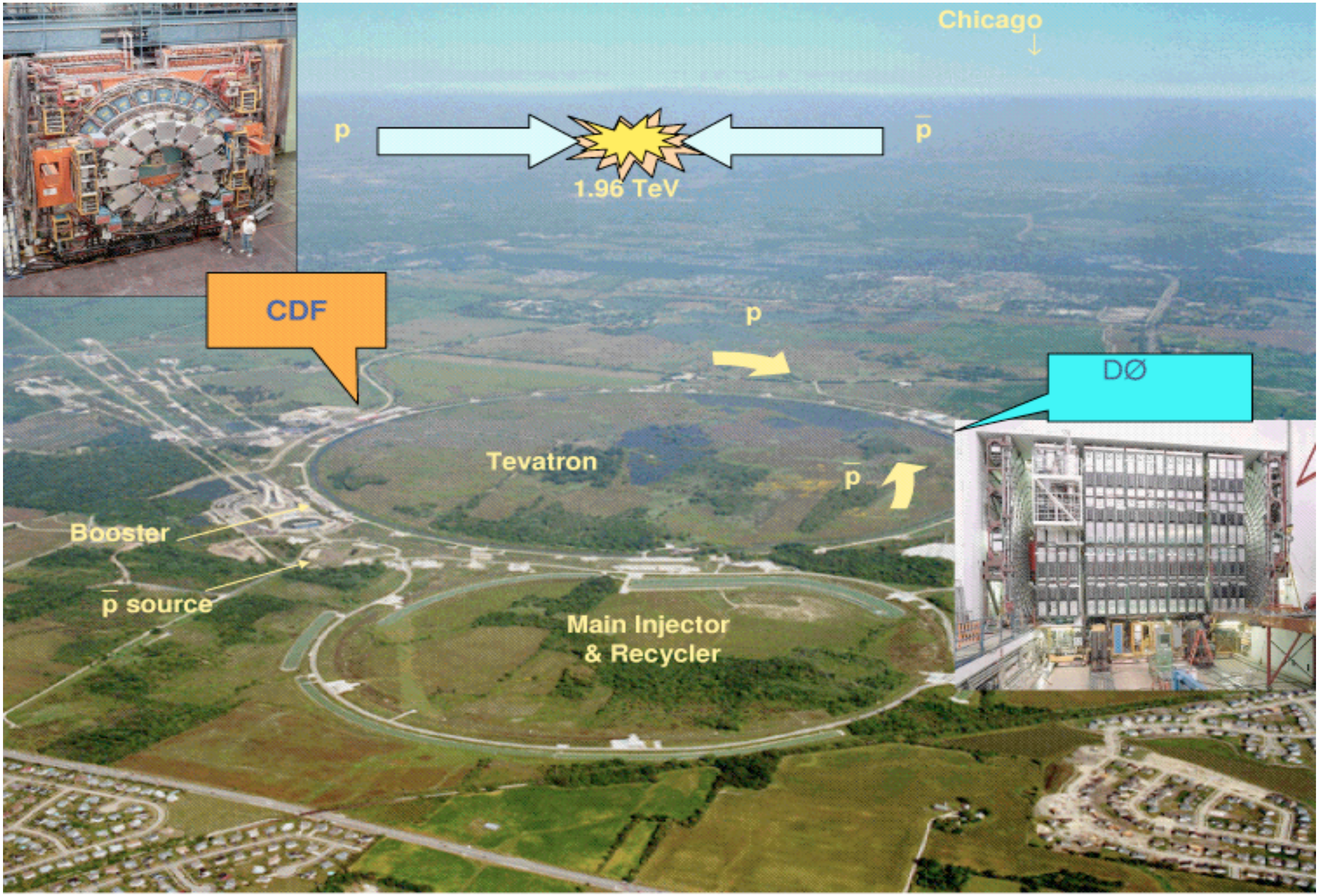
Proton-(Anti)proton Collisions

- Collisions:
  - At high energies we go inside the protons and antiprotons where we collide the internal quarks and gluons
- $E = mc^2$
  - Energy and mass are equivalent. With lots of energy we can produce lots of particles
  - 0.54 -0.63 TeV (SppS)
    - 1.8 -1.96 TeV (TeVatron)
      - 14 TeV (LHC)



- Production
  - In the collision process we can produce several types of particles and study their properties
- Decay
  - Some particles decay and the study of their daughters gives us insight on the nature of the interactions

The Experimental Apparatus: Fermilab



The Accelerator Chain (Fermilab)

At Fermilab, we start by accelerating protons in the Cockrof-Walton machine (750 KeV) to the Linac and Booster (up to 8 GeV)

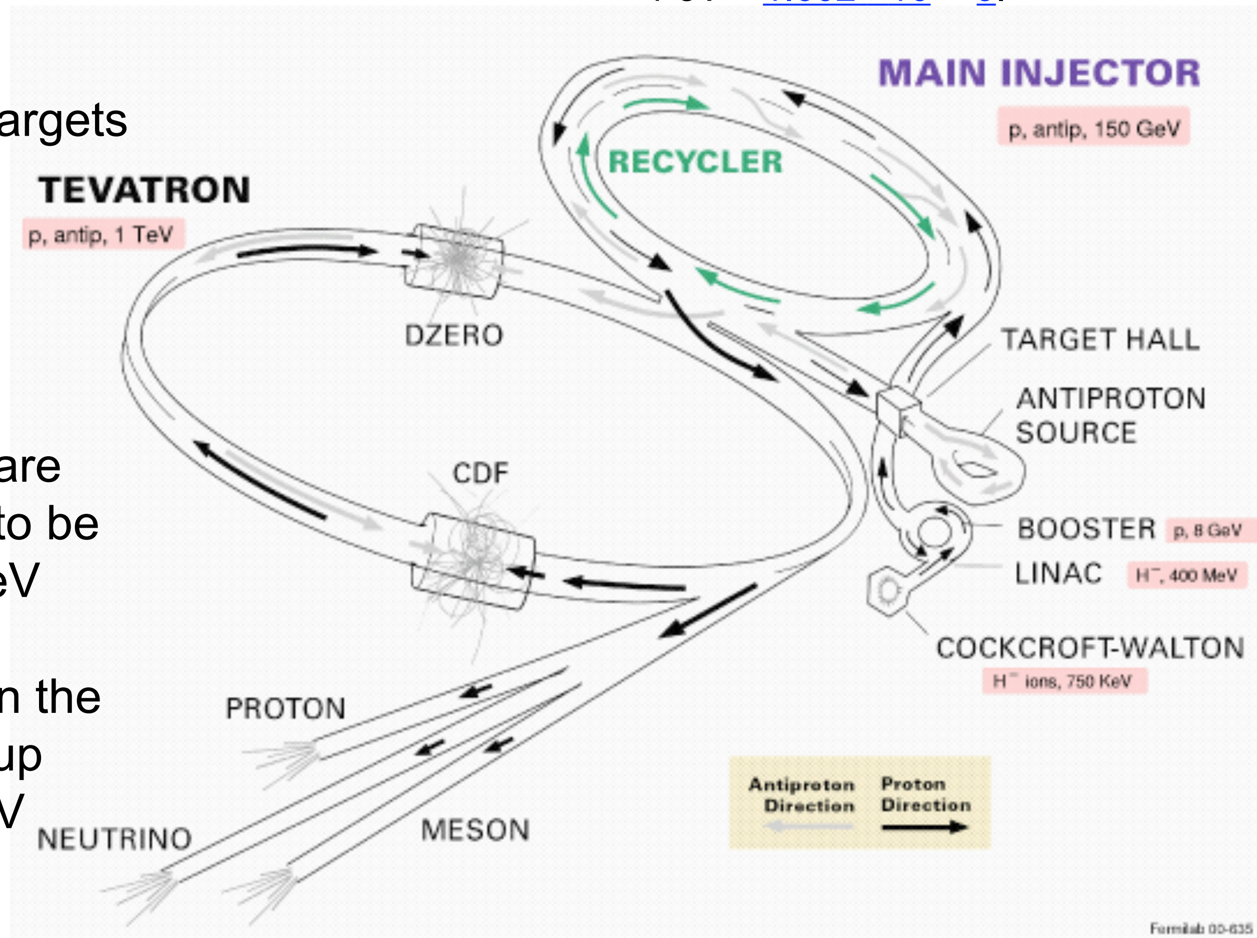
Some protons hit (gold) targets to make antiprotons

Antiprotons are stored (precious!)

Protons and antiprotons are sent to the main injector to be accelerated up to 150 GeV

They finally get injected in the TeVatron, which ramps up the beam energy to 1 TeV

An **electronvolt** (symbol: eV) is the amount of energy gained by a single unbound electron when it falls through an electrostatic potential difference of one volt. Very small amount of energy: 1 eV ≈ 1.602×10^{-19} J.



A small digression on Luminosity

The event rate $\mathcal{R}$ in a collider is proportional to the interaction cross section σ_{int}
The factor of proportionality is called instantaneous Luminosity $\mathcal{L}$

$$\boxed{\mathcal{R} = \sigma \times \mathcal{L}}$$

The instantaneous luminosity dependens on the number of bunches n_1 and n_2 of particles colliding, their frequency f and the gaussian beam profiles $\sigma_x \sigma_y$

$$\boxed{\mathcal{L} = f\, n_1 n_2 / 4\pi\sigma_x\sigma_y}$$

Typical values for past, present and future colliders:

- SppS: $10^{27\text{-}28}$ cm^{-2}s^{-1}
- TeVatron: 10^{32} cm^{-2}s^{-1}
- LHC: $10^{33\text{-}34}$ cm^{-2}s^{-1}

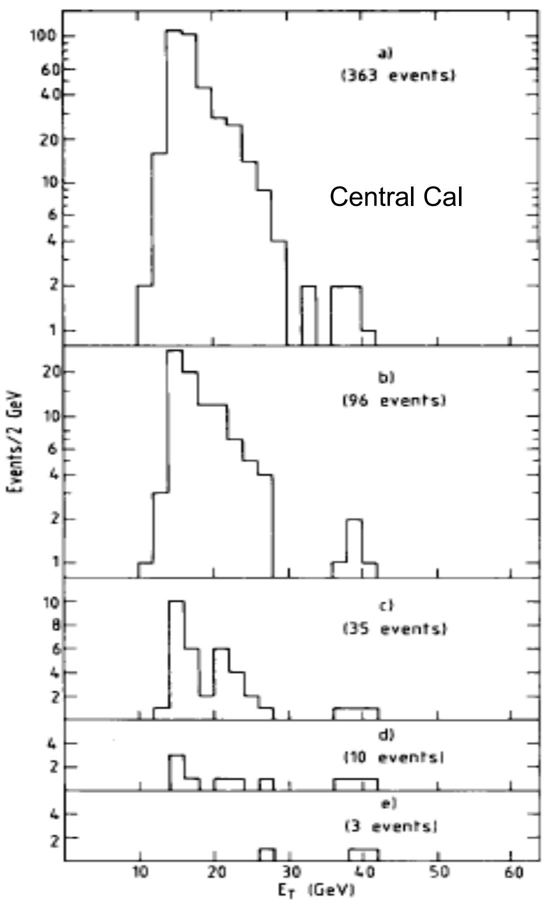
1picobarn(pb) = 10^{-36} cm^2

The real important quantity is the integrated Luminosity, expressed in units inverse to the cross section, pb^{-1}, fb^{-1}.
It tells us the number of events we can see during the lifetime of the experiment!

The discovery of the IVB (CERN 1983)

Proton-antiproton collisions at $\sqrt{s} = 540 GeV$ $\sim 20\ nb^{-1}$

Search for W bosons at UA2
4 events!



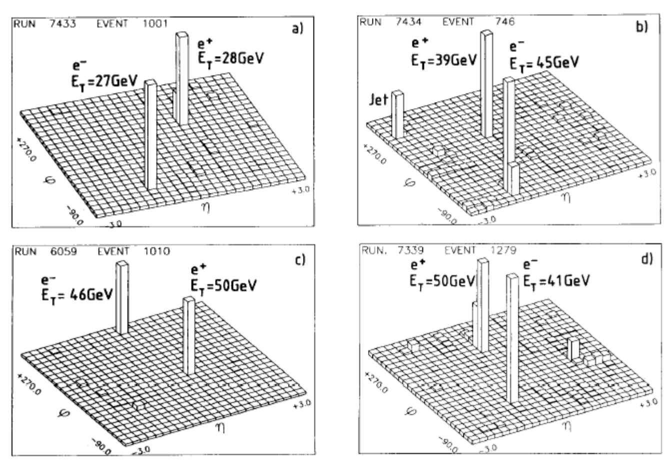
$$m_{W^\pm} = 82.1 \pm 1.7\ GeV$$

$$m_{Z^0} = 93.0 \pm 1.7\ GeV$$

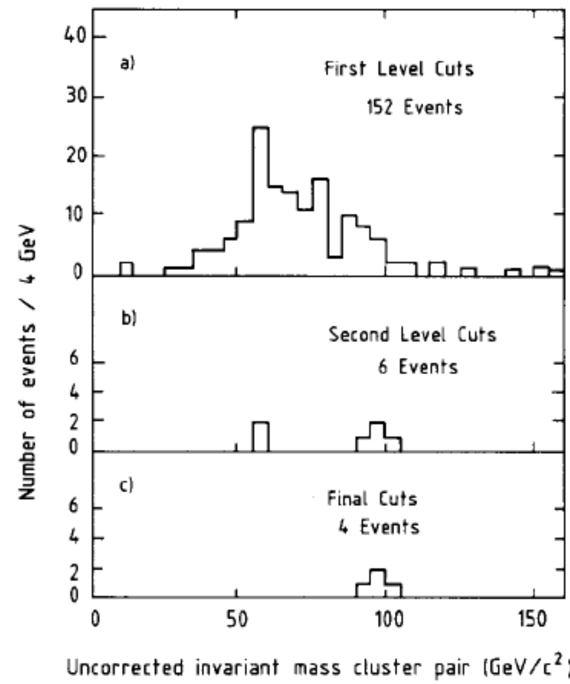
Current values (Particle Data Group 2006):

$$m_{W^\pm} = 80.403 \pm 0.029\ GeV$$

$$m_{Z^0} = 91.1876 \pm 0.0021\ GeV$$



Search for Z bosons at UA1
4 events!



The Detectors

The Experiment studies *interesting* collisions between protons and antiprotons
- events of interest are selected (trigger)
- the interaction of particle and matter is used to identify the physics objects

a multipurpose detector is like a large onion….

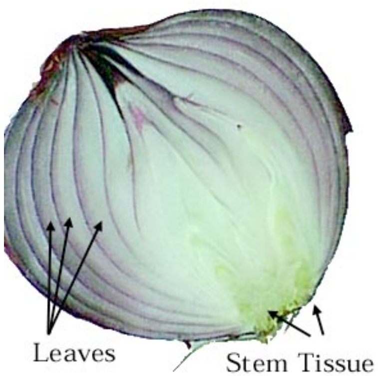
Charged particles leave tracks in a magnetic field (inner layer)

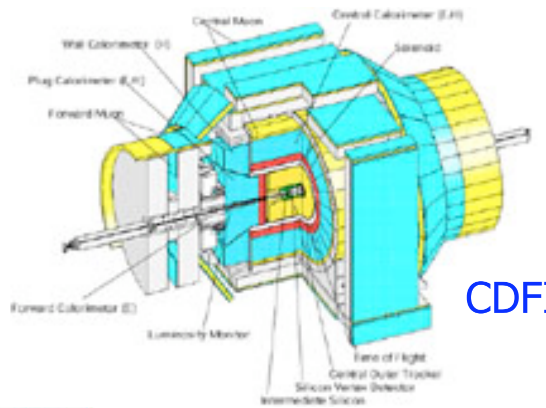
Most particles energies are absorbed by calorimeters (intermediate layers)

MIP's interact with the the most outside layers (muon chambers)

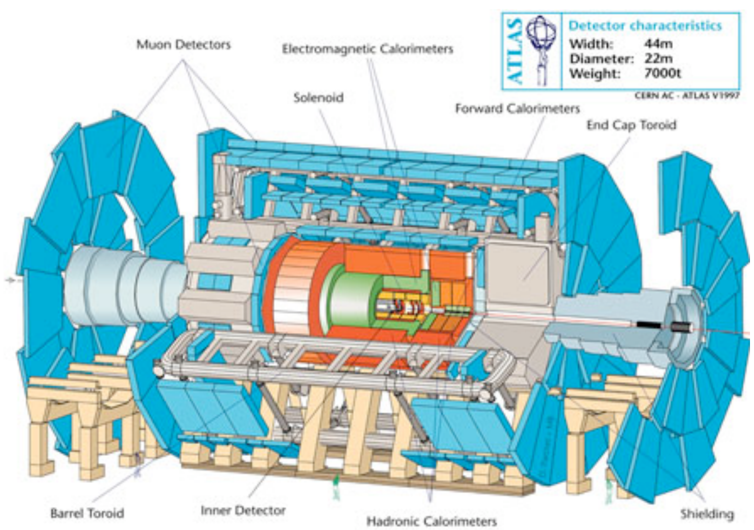
Electronics to read out each subsystem

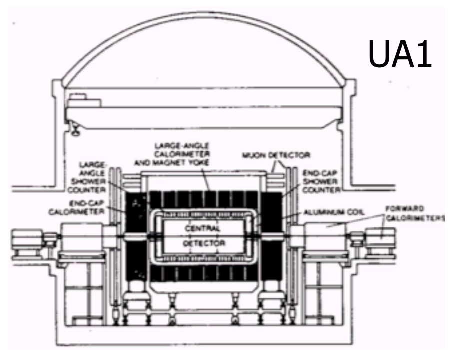
Computers to record and analyze data





CDFII

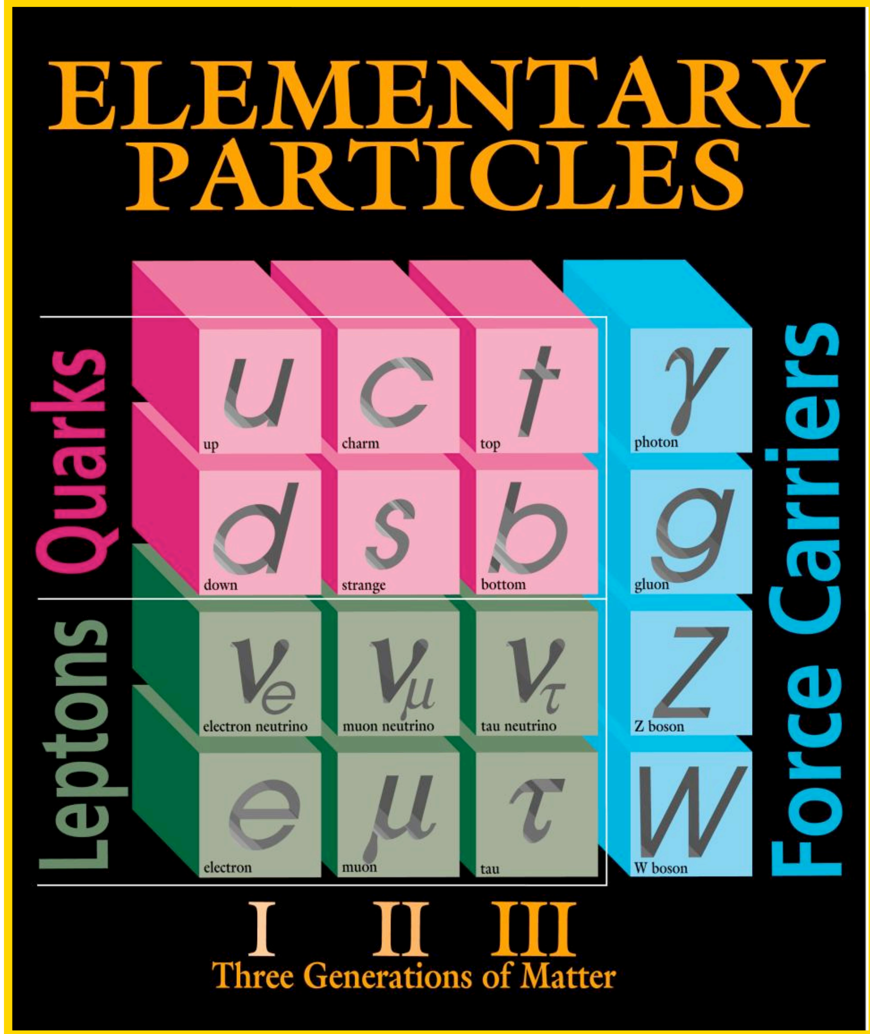




UA1

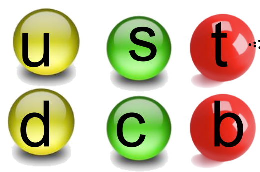
The Standard Model of Particle Physics

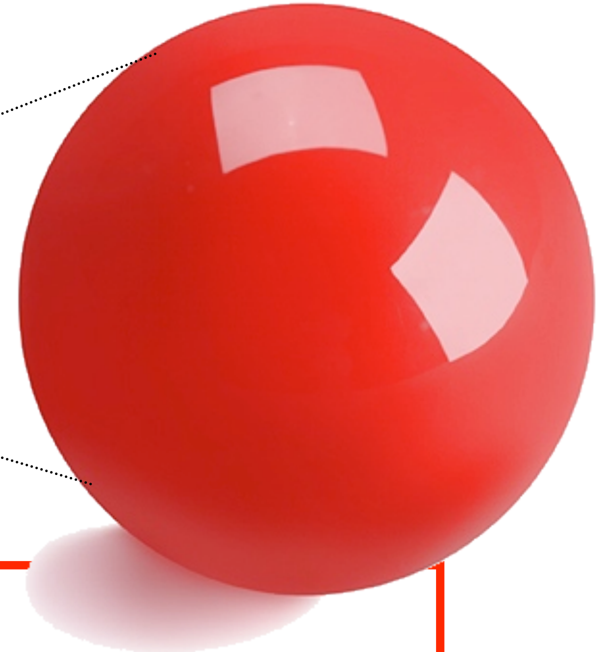
- The Standard Model describes the fundamental particles and the interactions between them
- Leptons like electrons are believed to be fundamental
- Hadrons are composite states of quarks and gluons;
  - Baryons (three quarks like protons and neutrons)
  - Mesons (a quark and one anti-quark)
- Force carriers are particles responsible for the interactions
- Collider experiments can identify all types of particles



Top Physics

The Top quark was discovered in 1995 at the TeVatron: flurry of measurements still ongoing



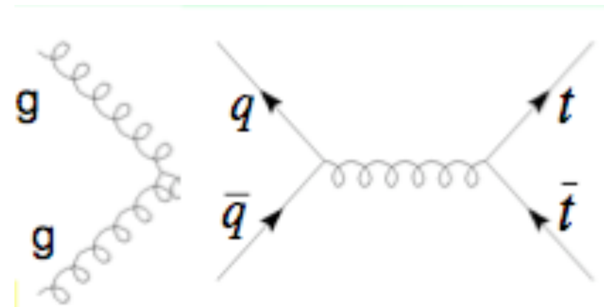


We still don't know all about it….

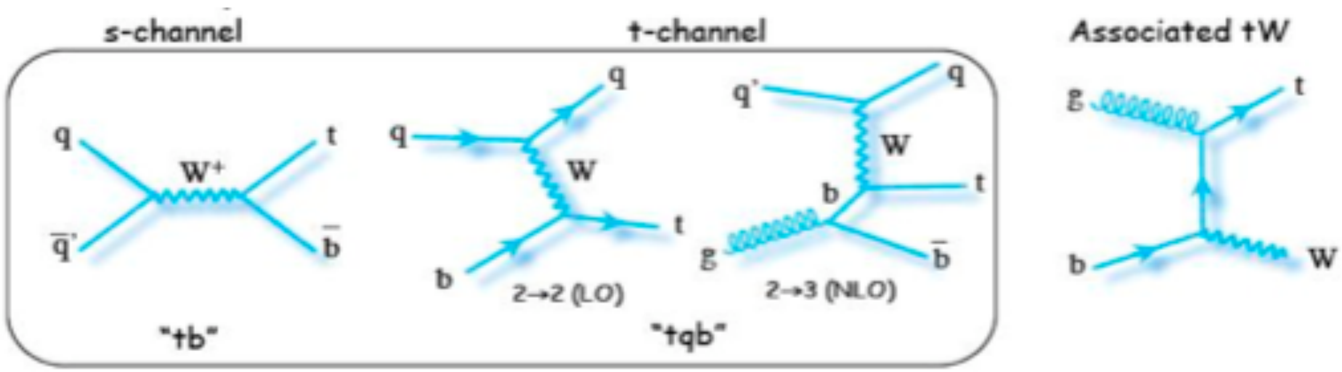
- Mass	Precision <2%
- Top width ~1.5 GeV	?
- Electric charge ⅔	-4/3 excluded @ 94% C.L. (preliminary)
- Spin ½	Not really tested – spin correlations
- BR($t \rightarrow Wb$) ~ 100%	At 20% level in 3 generations case
	FCNC: probed at the 10% level
- Production mechanisms	Electroweak production of single top

Top production modes

Strong Interactions:tt pair
Dominant mode: $\sigma_{NLO+NLL} = 6.7\ ^{+0.7}_{-0.9}$ pb (TeVatron))
Final state signatures understood



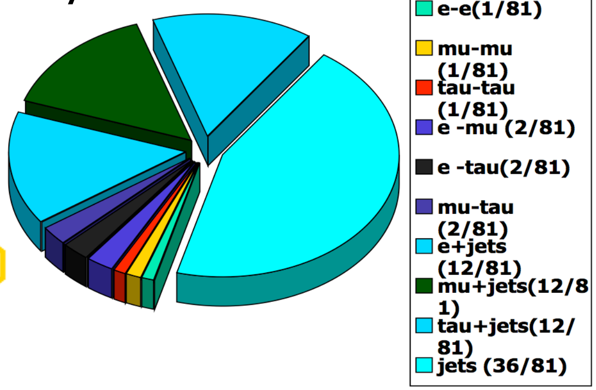
Weak Interactions: single top
Larger background, smaller cross section
Just observed

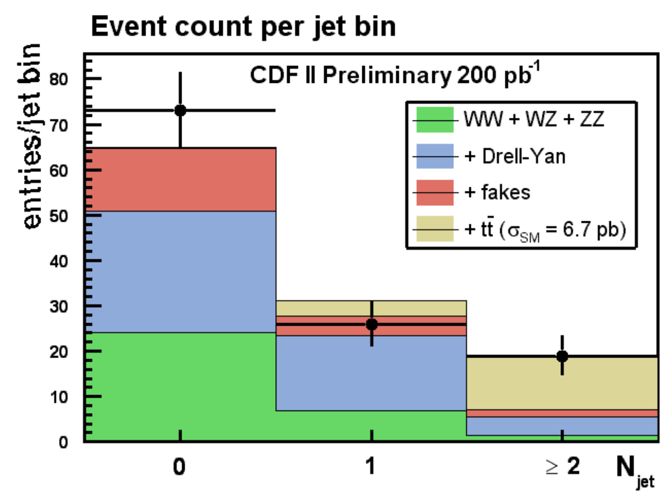


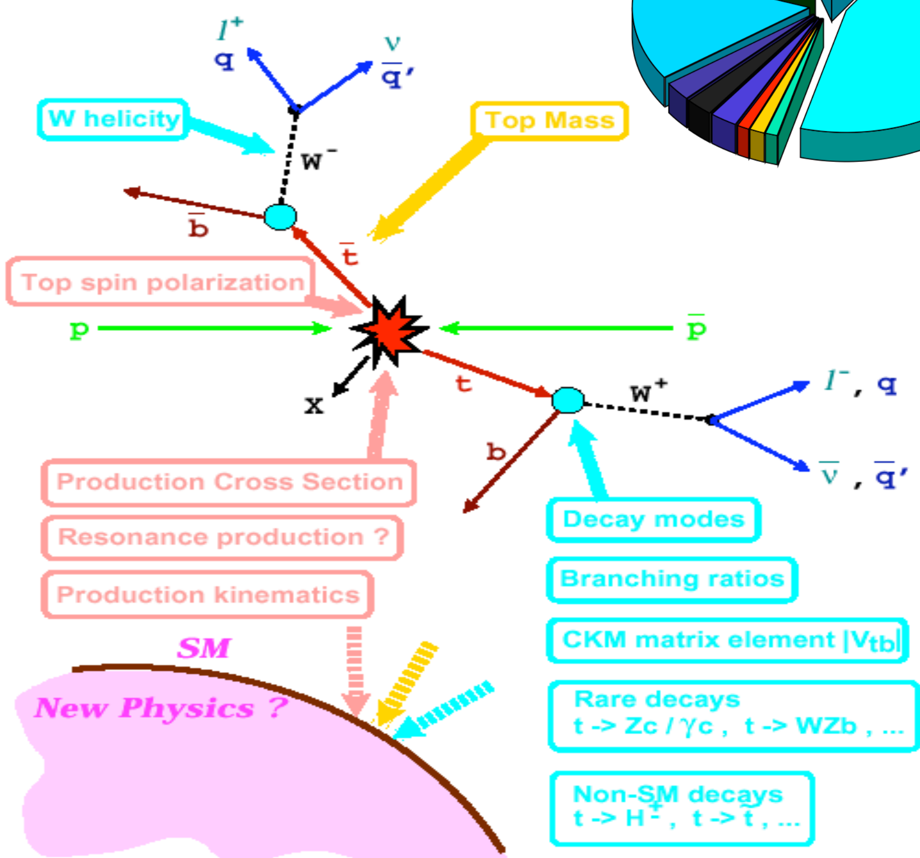
0.88±0.11 pb 1.98±0.24pb

Top Quark Pair Production

Complex final state including leptons, missing energy, jets and heavy flavors
W decay mode is used to classify
the final state







Signal is well visible in ≥ 2 jets bin

A host of measurements

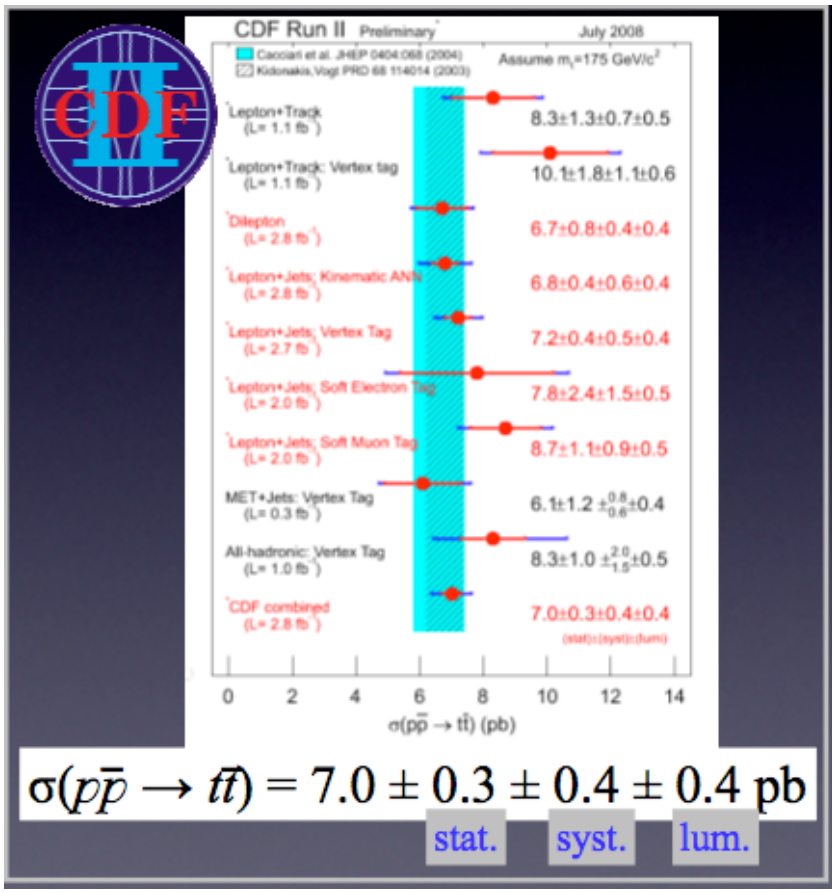
- -Mass and CrossSection
- -Wtb coupling
- -Searches for $H^+ \rightarrow tb, t \rightarrow H^+b$
- -Search for FCNC
- -Forward-backward asymmetry
- -M_{tt} distribution
- -Search for 4th generation top
- -W boson helicity

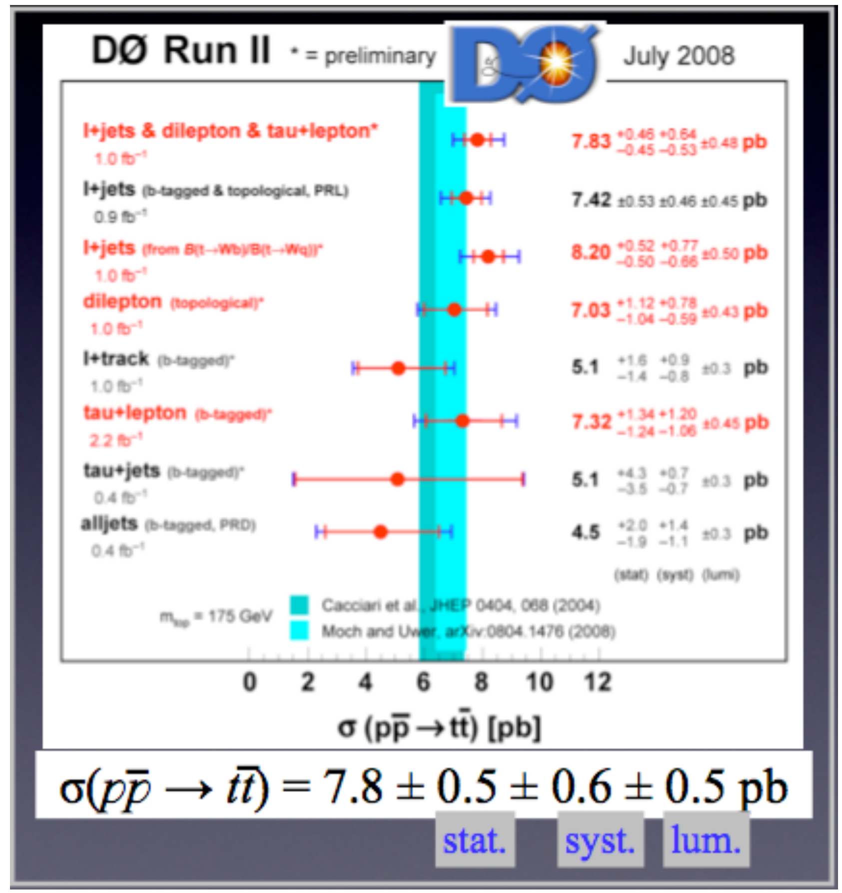
………..

Top Cross Section Measurement

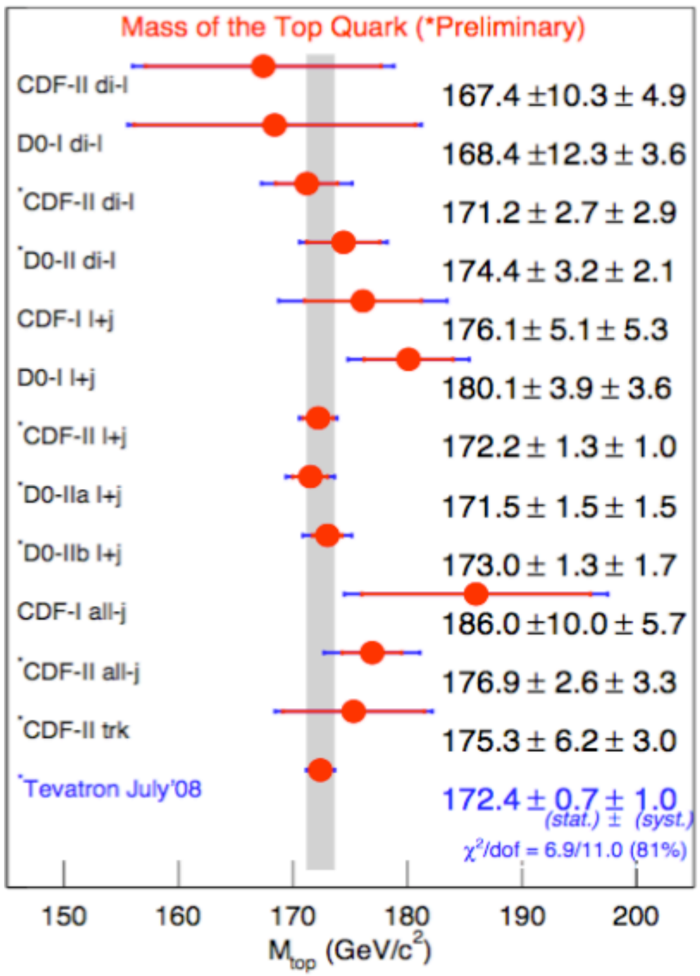
The cross section is measured in all final states: it is the first step of any study of the details of top quark properties.

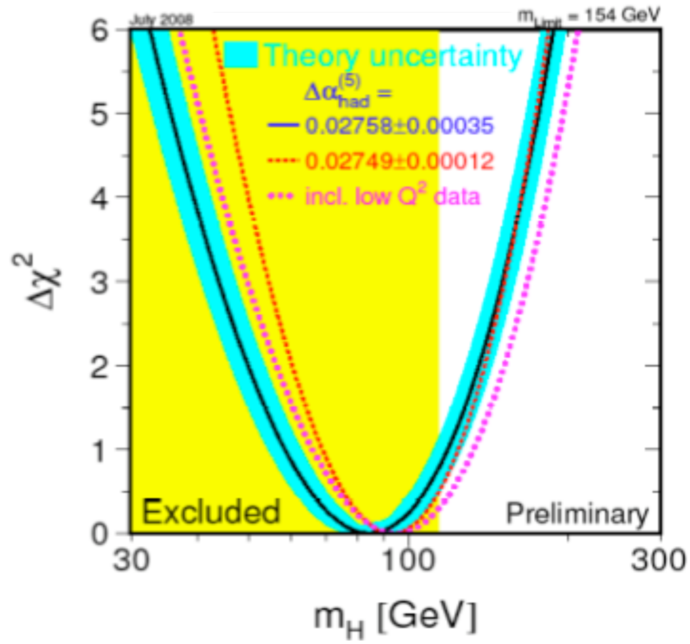
σ_{tt}=6.8±0.6 pb (Kidonakis, Vogt)
σ_{tt}=6.7+0.7-0.9 pb (Cacciari et al.)

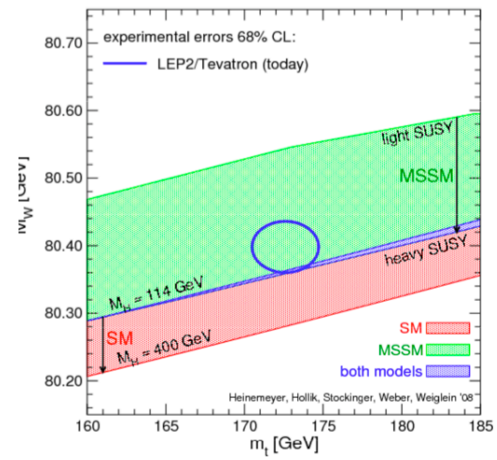




Top Mass Measurement







Light Higgs preferred

$$m_H < 154 \text{ GeV @ } 95\% \text{ C.L.}$$

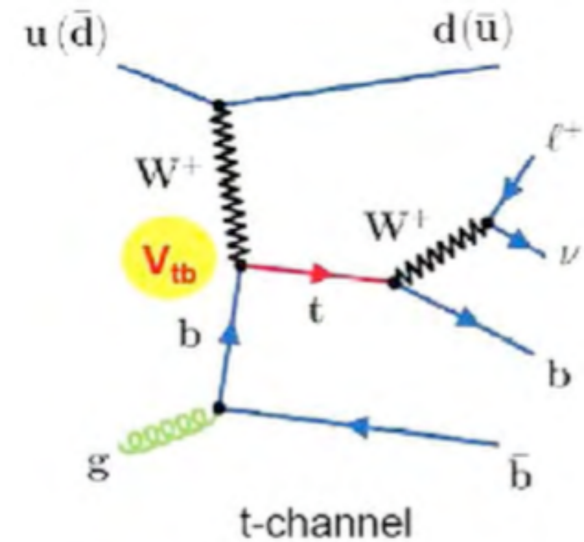
$$m_t = 172.4 \pm 0.7 \pm 1.0 \text{ GeV}$$

0.7% precision!

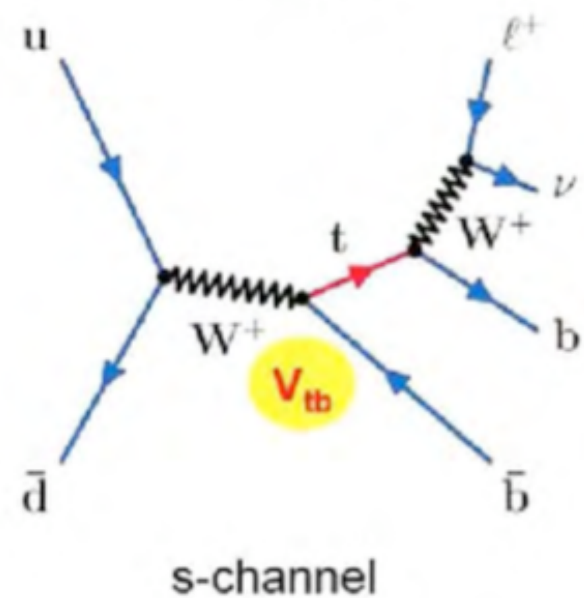
→ will be a legacy to LHC for the ***calibration of the jet E scale*** *of the Atlas and CMS detectors*

Single Top Production

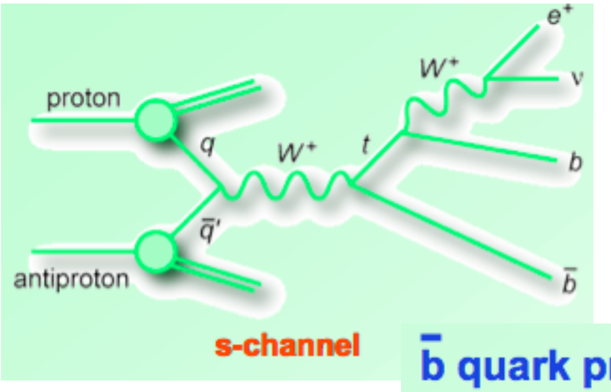
- Single top quark is produced via electroweak interaction but has not been observed SO FAR
  - ◇ σ_{SM}(t-channel/tqb) $= 1.98 \pm 0.25$ pb (m_{top} = 175 GeV)
  - ◇ σ_{SM}(s-channel/tb) $= 0.88 \pm 0.11$ pb (m_{top} = 175 GeV)
  - ◇ $\sigma_{SM}(t\bar{t}) = 6.7 \pm 0.8$ pb (via strong interaction)
  - ◇ B.W. Harris *et al.*, Phys. Rev. D 66, 054024 (2002)
    Z. Sullivan, Phys. Rev. D70, 114012 (2004)



- Test of the Standard Model
  - ◇ Direct measurement of $|V_{tb}|$
  - ◇ Top quark properties: polarization, spin, W helicity,...
  - ◇ Same final state as WH
- Sensitive to new physics
  - ◇ Search for W', H^+ (s-channel signature)
  - ◇ Search for FCNC,...



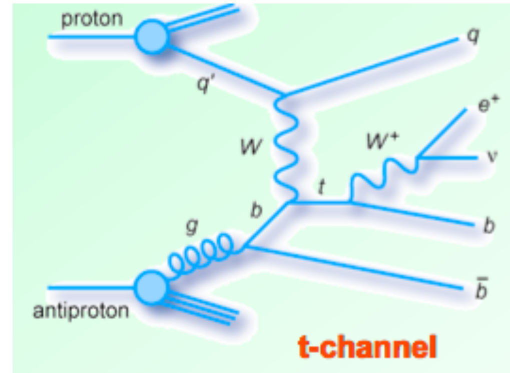
Signatures and Backgrounds



$\bar{b}$ quark produced WITH the top

b quark from the top decay

lepton + Missing E_T



b quark from the top decay

lepton + Missing E_T

extra light quark

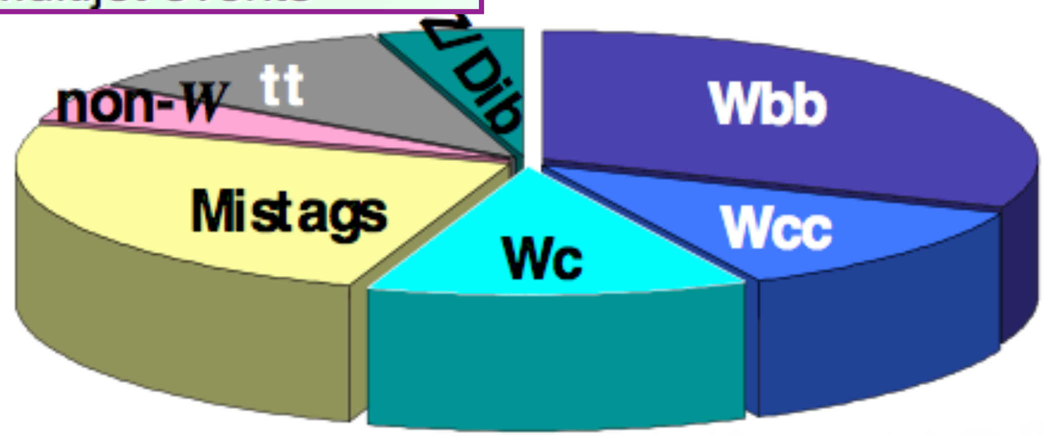
at NLO an additional $\bar{b}$ is radiated

- Top decays most of the times to Wb
- W + 2 or 3 (4 in DØ) energetic jets
- One high p_T isolated lepton (electron or muon) from the leptonic decay of the W
- Large missing transverse energy, $\not{E}_T$, from the neutrino
- At least one jet identified as b-tagged
- Main backgrounds: W+Heavy Flavor, W+mistags, $t\bar{t}$, QCD, diboson

W/Z + jets production

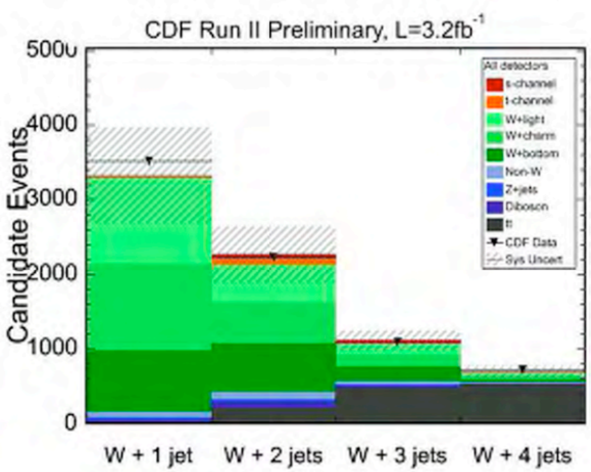
Top pair production

Multijet events



The Challenge

Single Top is buried under a large background
A counting experiment is NOT possible



Percentage of single top *tb+tqb* selected events and S:B ratio (white squares = no plans to analyze)

Electron + Muon	1 jet	2 jets	3 jets	4 jets	≥ 5 jets
0 tags	10% 1 : 3,200	25% 1 : 390	12% 1 : 300	3% 1 : 270	1% 1 : 230
1 tag	6% 1 : 100	21% 1 : 20	11% 1 : 25	3% 1 : 40	1% 1 : 53
2 tags		3% 1 : 11	2% 1 : 15	1% 1 : 38	0% 1 : 43

Multivariate analysis will discriminate between the single top signal and the background
There is no single observable to single out single top!

On multivariate analysis techniques

Cut-based analysis strategies are not powerful enough to discriminate very small signal buried under heavy background

- -Limited statistical power : very few events surviving the cuts
- -Background-like events do not survive cuts and/or increase uncertainty

Multivariate techniques should increase the discriminating power since they use all available measurements to extract more information about the events that are selected.

- -Issues with correlations
- -Issues with systematic uncertainty treatment
- -Complexity of training

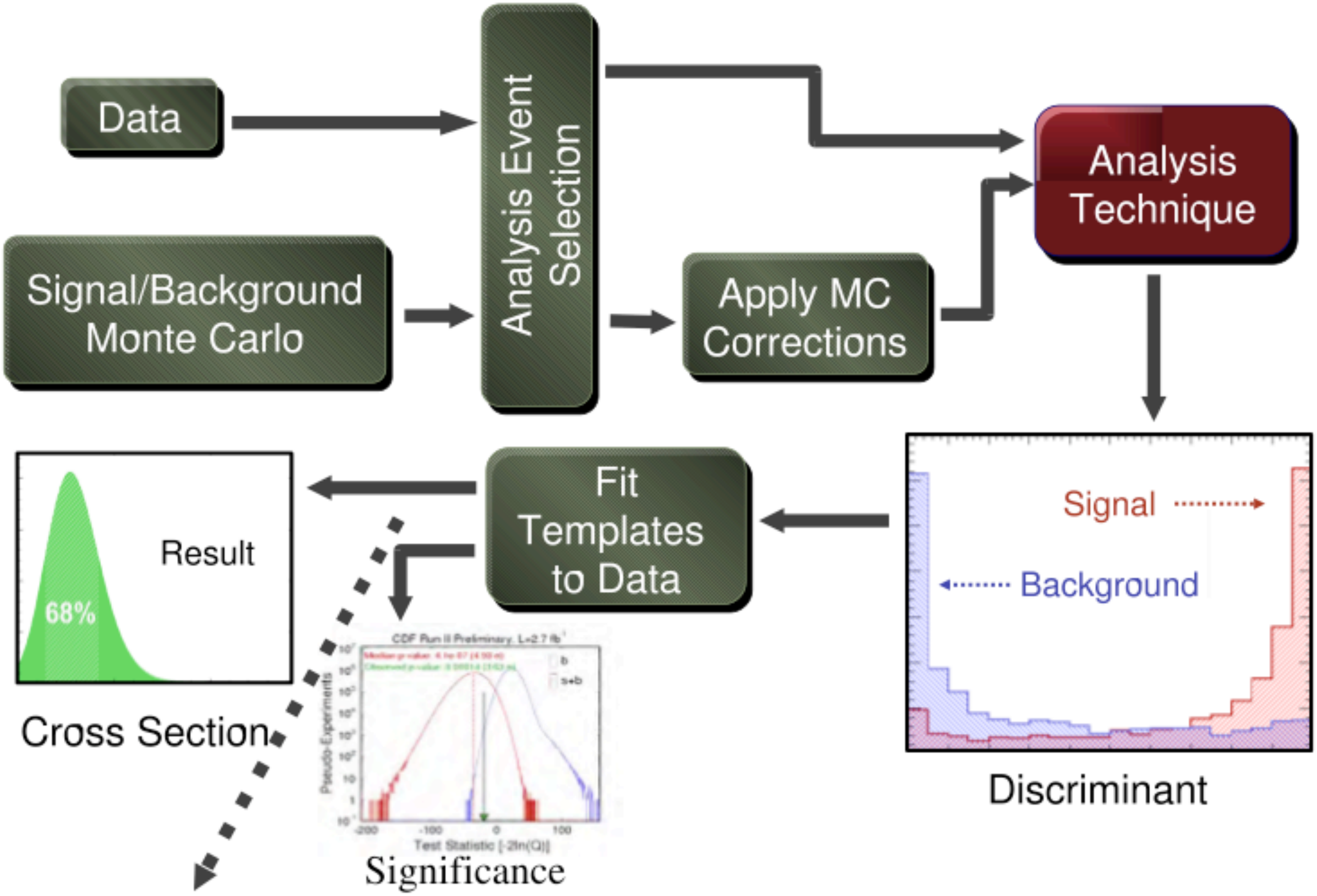
Comparisons with cut-based analysis

	s-channel		*t*-channel	
SM prediction	$0.88^{+0.07}_{-0.06}$ pb		$1.98^{+0.23}_{-0.18}$ pb	
	Expected limits		Observed limits	
	s-channel	*t*-channel	*s*-channel	*t*-channel
Initial selection	14.5	16.5	13.0	13.6
Cut-based	9.8	12.4	10.6	11.3

Table 1: Expected SM production cross sections. Expected and observed upper limits (in picobarns) at the 95% confidence level on the production cross sections of single top quarks after event selection and with the cut-based analysis. Results correspond to 230 pb^{-1} of analysed data collected with the DØ detector.

	Expected limits		Observed limits	
	s-channel	*t*-channel	*s*-channel	*t*-channel
Likelihood	3.3	4.3	5.0	4.4
Neural network	4.5	5.8	6.4	5.0
Decision tree	4.5	6.4	8.3	8.1

Analysis Strategy



Rate/shape systematic uncertainties: implemented as nuisance parameters

The Methods

Likelihood Discriminants

Let's take a vector of measurements X= {x_i} for different discriminating variables x_i

The likelihood of the event is given by:

$$\mathscr{L}(\vec{x}) = \frac{\mathscr{P}_{\text{signal}}(\vec{x})}{\mathscr{P}_{\text{signal}}(\vec{x}) + \mathscr{P}_{\text{background}}(\vec{x})}$$

$\mathcal{L}$ = 1 for Signal

$\mathcal{L}$ = 0 for Background

$$\mathscr{P}_{\text{signal}}(\vec{x}) = \prod_{i}^{N_{\text{variables}}} P_{\text{signal}}(x_i), \quad \mathscr{P}_{\text{background}}(\vec{x}) = \sum_{j}^{N_{\text{backgrounds}}} f_j \prod_{i}^{N_{\text{variables}}} P_{j\ \text{background}}(x_i),$$

The probability functions are determined from MC one-dimensional distributions of the input variables

Potential correlations between variables are not taken into account.

Different likelihoods are built for signal and backgrounds

Data are fitted to the resulting templates

No training needed

The Methods (cont'd)

Neural Networks

The structure of the network consists of a layer of input nodes, a single layer of hidden nodes and one output node.

One input node for each discriminating variable x_i

Hidden node: $$n_k = \frac{1}{1+\exp^{-\sum w_{ik} x_i}}$$

w_{ik} is the weight of the variable x_i to node n_k

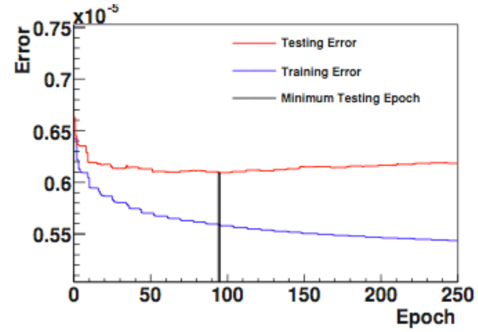
Output Node is a linear combination of hidden nodes. $O = \sum w_k n_k$

w_{ik} and w_k are determined through training with an iterative procedure that minimizes:

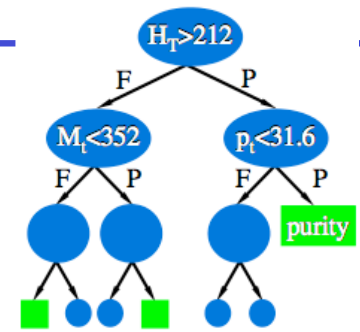
$$\text{Error} = \sum_j^{N_{\text{events}}} W_j^2 (O_j^{\text{desired}} - O_j^{\text{observed}})^2.$$

where O is desired/observed output for signal and background.

60% events used for training, 40% for testing



The Methods: Decision Trees



<u>Machine Learning Technique</u>

A simple cut-based analysis is extended to a multivariate analysis by continuing to analyze events that fail a particular criterion

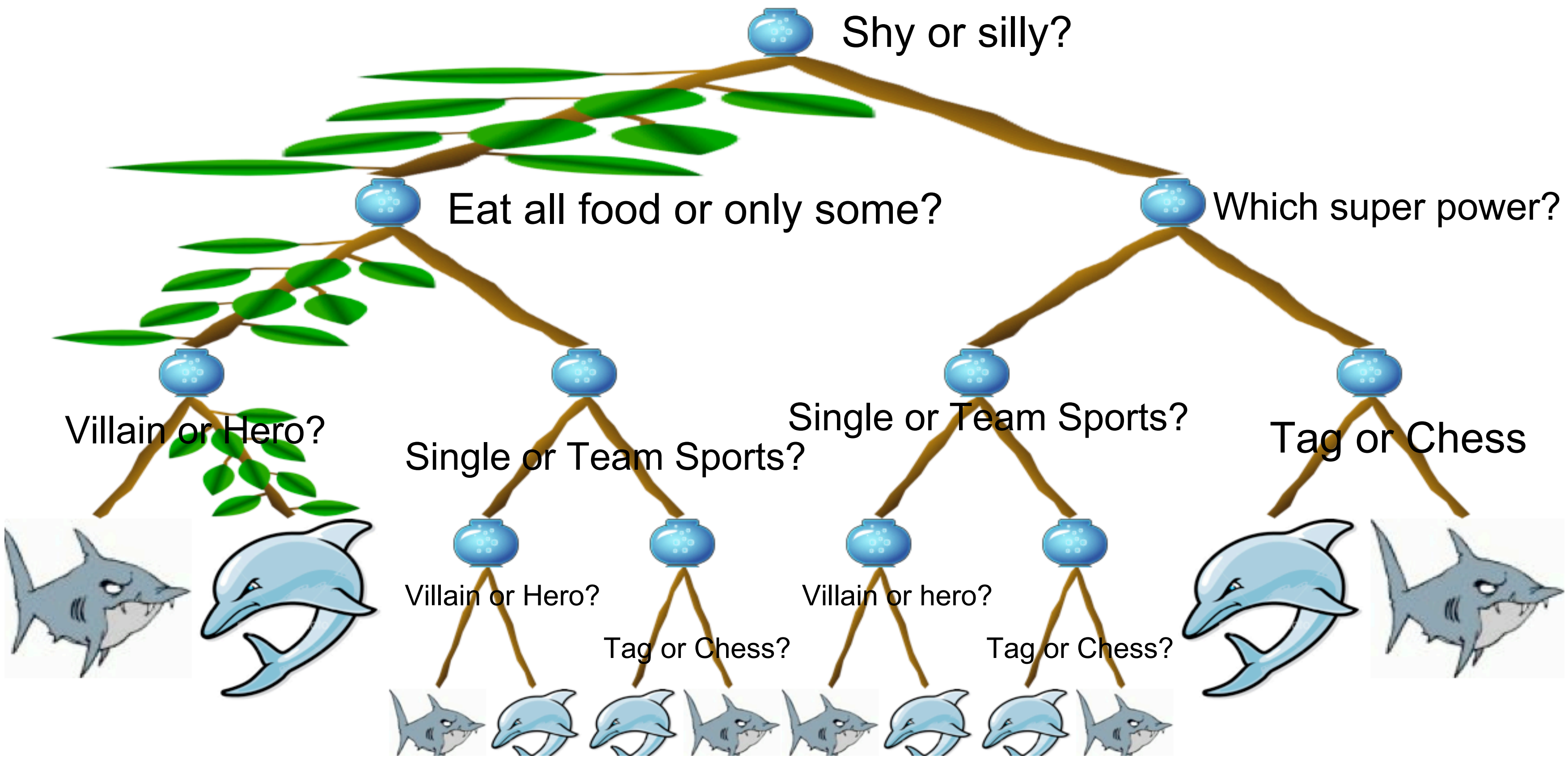
An initial sample made of known signal and background forms the root of the Tree.
Given a list of variables all events are sorted in turn according to each variable.

For each x_i the splitting value that gives the best separation of the events in 2 child nodes (one signal-like the other background-like) is found. The variable and split value giving the best separation are selected and two nodes are created, corresponding to the events satisfying the split criterion (P or F)

The algorithm is applied recursively to the two child nodes. When the splitting stops, the terminal node is called a leaf, with an associated purity (weighted signal fraction of the training sample in this node)

When an new event goes through the tree, its properties are compared to the criterion at each node until it reaches a leaf.

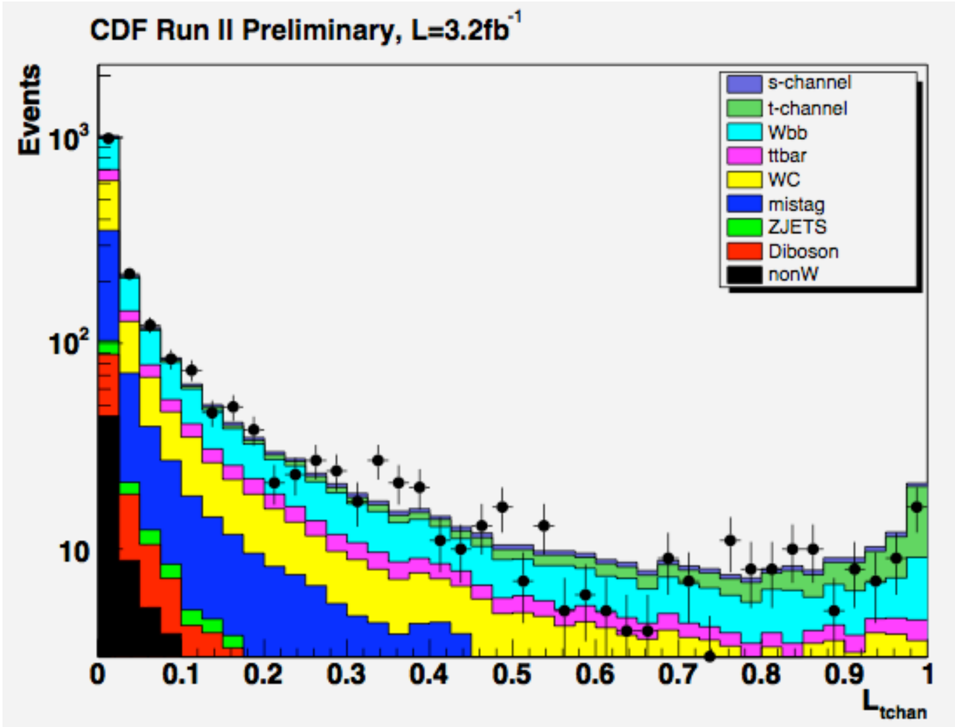
Decision Trees outside HEP…



Sharks and Dolphins Decision Tree (chickadee)

Results: Likelihood

- Combines several sensitive variables into a single one
- 7 (10) variables used in the 2 (3) jet bin: H_T, $Q\times\eta$, M_{jj}, cos(l, j), log (ME_{t-chan})...



Lum. (fb^{-1})	Exp. sign.	Obs. sign.	Cross Section (pb)
3.2	4.0σ	2.4σ	$1.6^{+0.8}_{-0.7}$

Result: Matrix Element

- Compute, for each event, the probability for signal and background hypotheses

- Use full event kinematic information

- Calculate probabilities for signal and backgrounds

Inputs: lepton and jet 4-vectors – no other information is needed!

LO Matrix Elements: different for each process

Transfer Function: accounts for effects in energy measurement

$$P(p_l^m, p_{j1}^m, p_{j2}^m) = \frac{1}{s}\int d\tilde{\sigma}_{j1}\, d\tilde{\sigma}_{j2}\, dp_{\sigma}^z \sum_{comb} f_4 |M(p_i^m)|^2 \frac{f(q_1)f(q_2)}{|q_1||q_2|} W_{jet}(E_{jet}, E_{part})$$

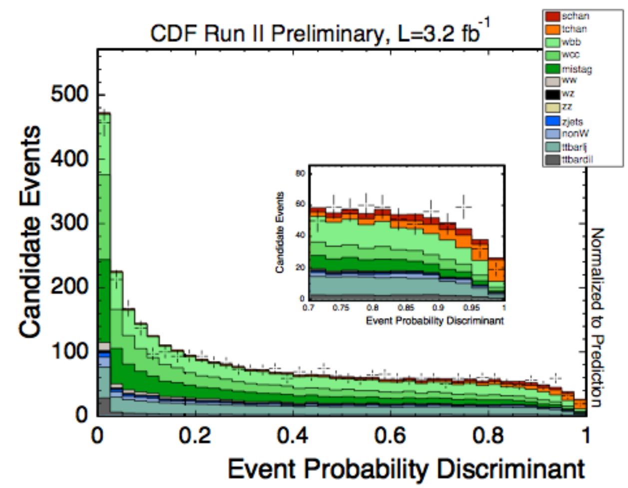
Phase Space Factor: integrate over unknown or poorly measured quantities

Parton Distribution Functions

- Build a discriminant

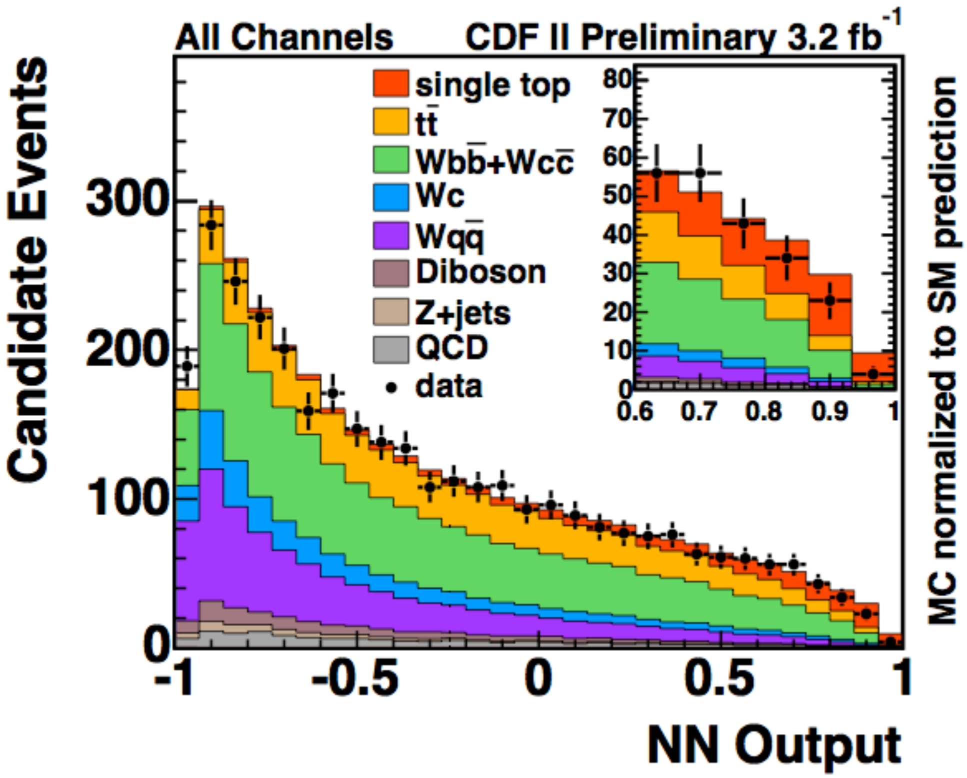
CDF
$$EPD = \frac{b \cdot P_{sig}(\vec{x})}{b \cdot P_{sig}(\vec{x}) + b \cdot P_{b-bkg}(\vec{x}) + (1-b) \cdot P_{nonb-bkg}(\vec{x})}$$

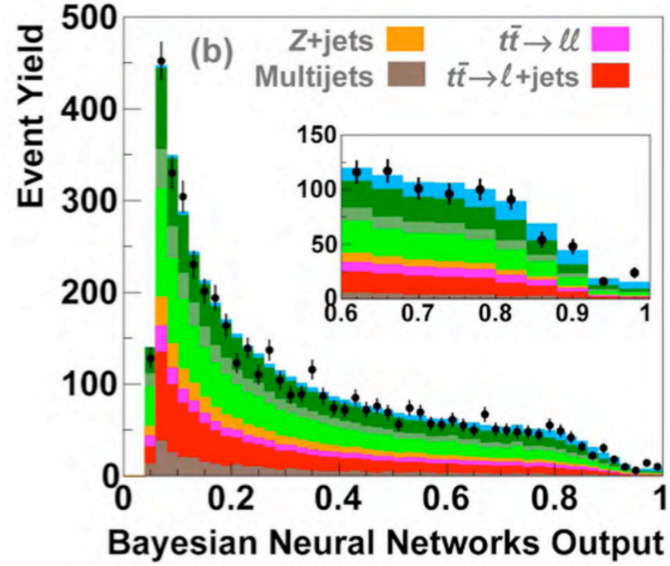
DØ
$$D(\vec{x}) = \frac{P_{sig}(\vec{x})}{P_{sig}(\vec{x}) + P_{bkg}(\vec{x})},$$ (separate for s and t channels)



ME	Lum. (fb^{-1})	Exp. sign.	Obs. sign.	Cross Section (pb)
CDF	3.2	4.9σ	4.3σ	$2.5^{+0.7}_{-0.6}$
DØ	2.3	4.1σ	4.9σ	$4.3^{+1.0}_{-1.2}$

Results: Neural Net

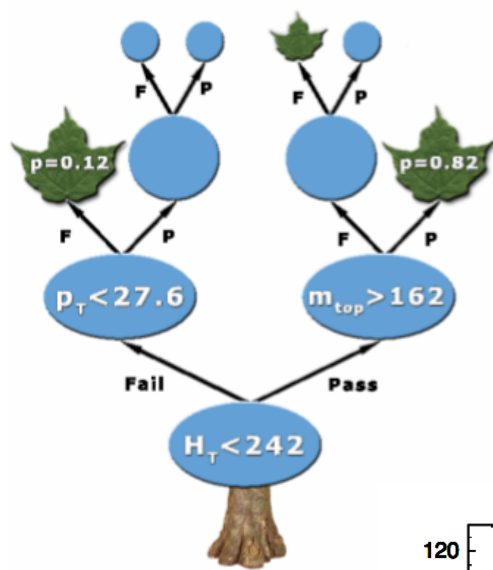


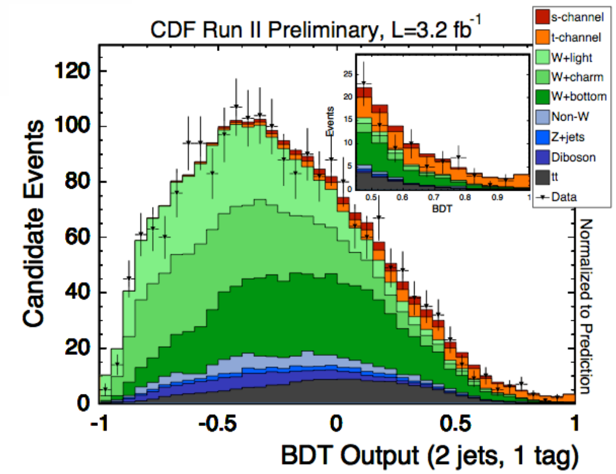


	Lum. (fb^{-1})	Exp. sign.	Obs. sign.	Cross Section (pb)
CDF	3.2	5.2σ	3.5σ	1.8 ± 0.6
D0	2.3	4.1σ	5.2σ	$4.7^{+1.2}_{-0.9}$

Results: Boosted Decision Tree

- Sequence of binary splits using the discriminating variable which gives best sig-bkg separation
- Leaf nodes are classified as sig-like or bkg-like depending on majority of events ending up in the respective leaf
- Use large number of input variables
  - ◇ Non-discriminating variables are automatically ignored, but do not degrade the performance
- Boosting algorithm improves the discrimination power and statistical stability
  - ◇ Events misclassified during a DT training are given a higher weight in the next DT training





BDT	Lum. (fb^{-1})	Exp. sign.	Obs. sign.	Cross Section (pb)
CDF	3.2	5.2σ	3.5σ	$2.1^{+0.7}_{-0.6}$
DØ	2.3	4.3σ	4.6σ	$3.7^{+1.0}_{-0.8}$

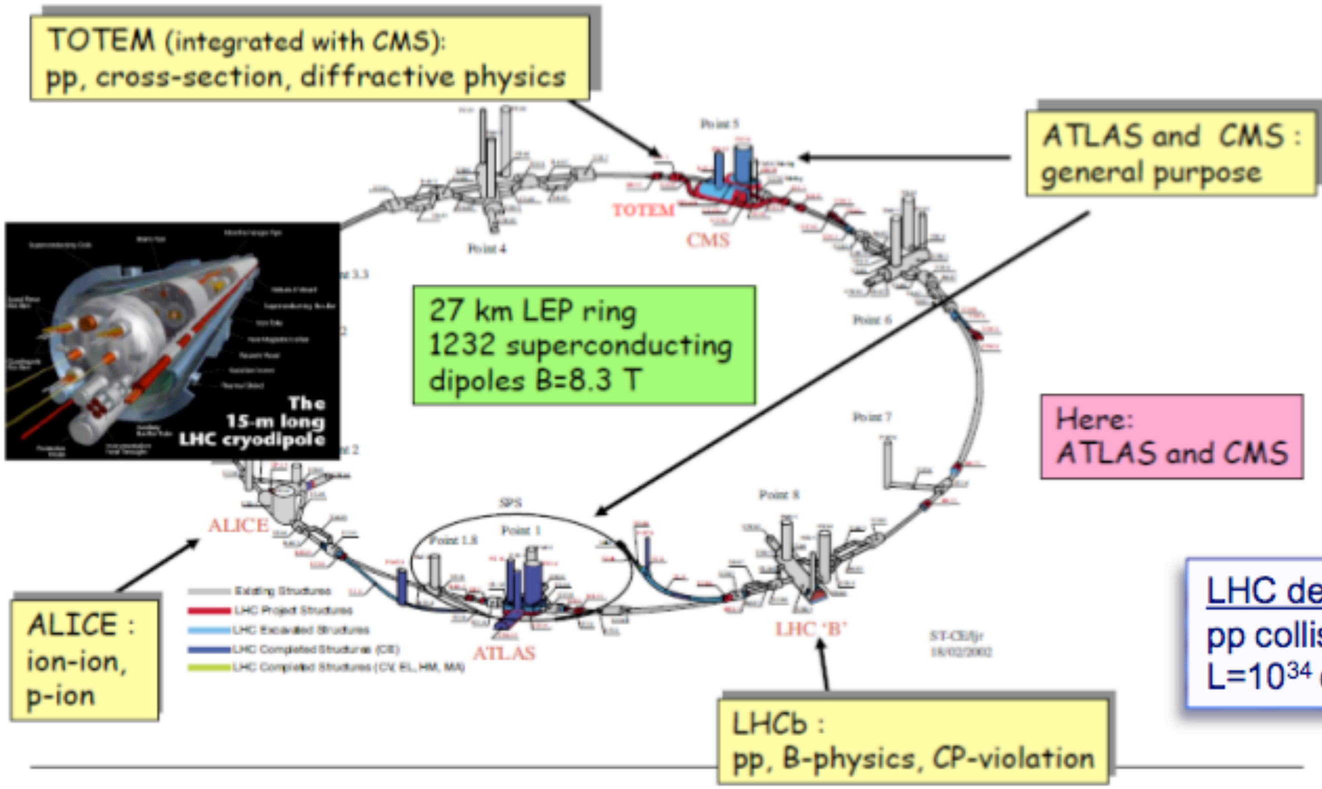
Combination

- Each experiment combines the individual results
- DØ Use the NN, BDT and ME discriminant outputs to create a second layer combination NN discriminant
  - ◇ Crosscheck with BLUE (Best Linear Unbiased Estimator)
- CDF NEAT: Neuro Evolution of Augmenting Topologies
  - ◇ Superdiscriminant that uses output discriminant of individual analysis (LF, NN, ME, BDT, LF-schan) as input
  - ◇ Candidate networks compete against each other
  - ◇ Network topology, weights, output histogram binning, includes systematic errors in optimization procedure (using genetic algorithms)
  - ◇ The final network is chosen based on the expected p-value

Comb	Lum. (fb^{-1})	Exp. sign.	Obs. sign.	Cross Section (pb)
CDF*	3.2	5.9σ	5.0σ	$2.3^{+0.6}_{-0.5}$
DØ	2.3	4.5σ	5.0σ	3.9 ± 0.9

* SD combined with $\not\!\!E_T$+jets analysis

The next frontier:LHC



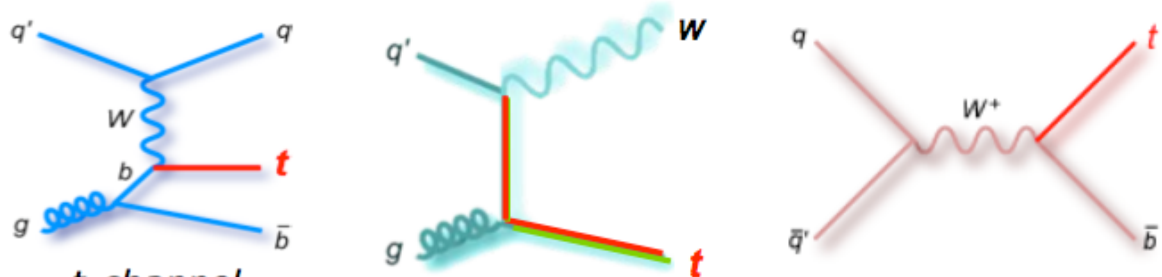
LHC design parameters:
pp collisions at $\sqrt{s}$=14TeV
L=10^{34} cm^{-2}s^{-1}

Startup scenario:

- Machine cold by September-> first collisions late in October
- Beam physics running during winter 2009- autumn 2010
- start with 450 GeV up to 5 TeV per beam;
- goal: integrate ~200 pb^{-1}

Prospects for single top at LHC

- The cross section hierarchy is different at LHC

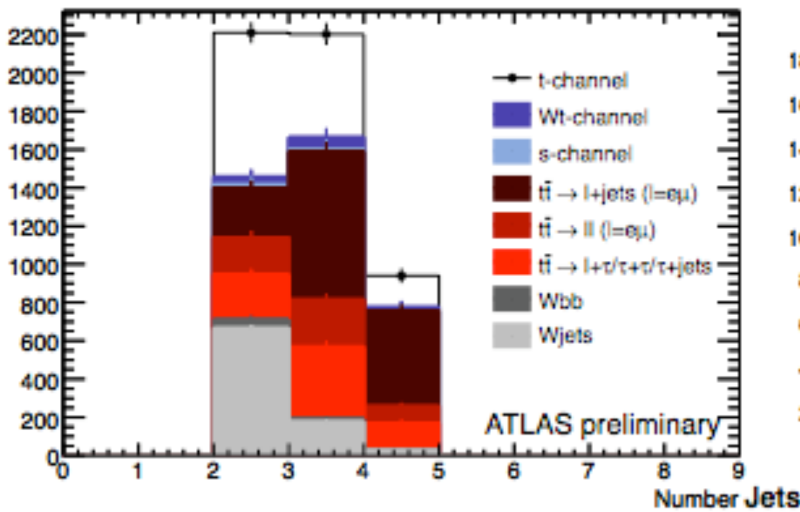


t-channel
σ = 240pb

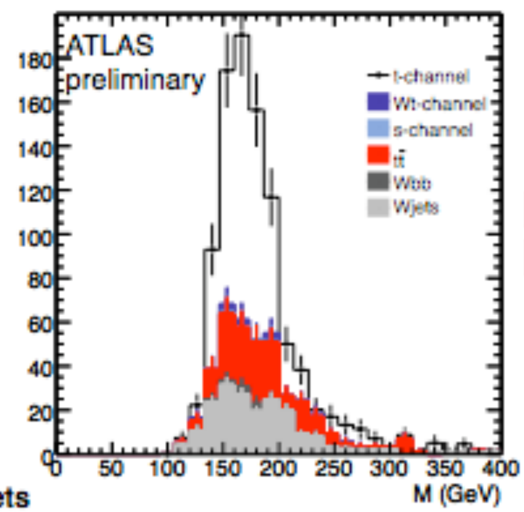
tW production
σ = 60pb

s-channel
σ = 10pb

Selected events



After BDT



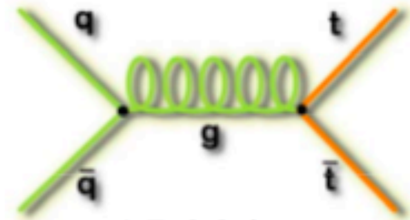
t-channel

- BDT very effective for single top.
- Lacking data driven bkg estimation: QCD estimation!

Conclusions on Single Top

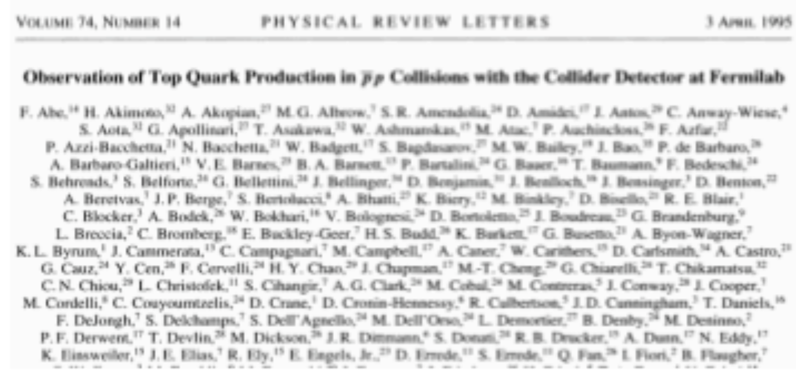
- The search for the top quark lasted almost two decades

  The big surprise was the huge mass!



σ_{NLO} = 6.7±0.8pb (m_t=175GeV/c^2)

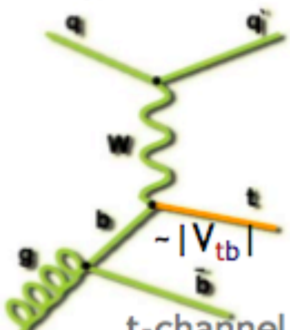
Discovered March 1995!


VOLUME 74, NUMBER 14 PHYSICAL REVIEW LETTERS 3 APRIL 1995

Observation of Top Quark Production in $\bar{p}p$ Collisions with the Collider Detector at Fermilab

- Single top quark production also predicted by the SM through an electroweak vertex (σ_{st} ~ 0.4 σ_{tt})

Discovered March 2009!



t-channel

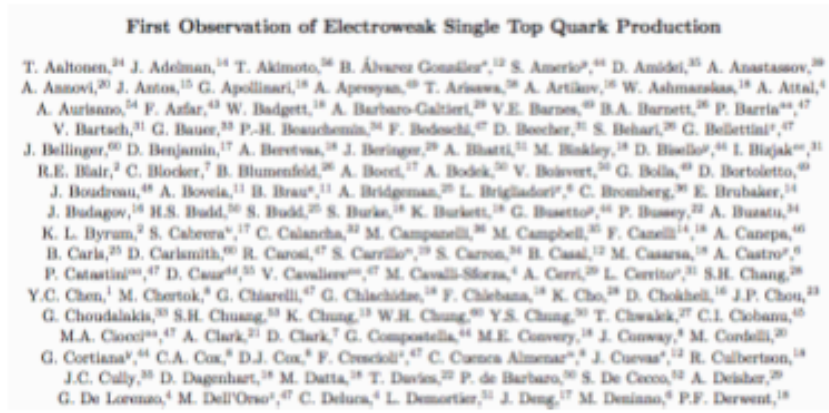
σ_{NLO} = 1.98±0.21pb

(m_t=175 GeV/c^2)

s-channel

σ_{NLO} = 0.88±0.07pb

B.W. Harris et al., Phys. Rev. D66, 054024
Z. Sullivan, Phys. Rev. D70, 114012 (2004).
Compatible Results;
Campbell/Ellis/Tramontano, Phys. Rev. D70, 094012 (2004).
N. Kidonakis, Phys. Rev. D74, 114012 (2006).



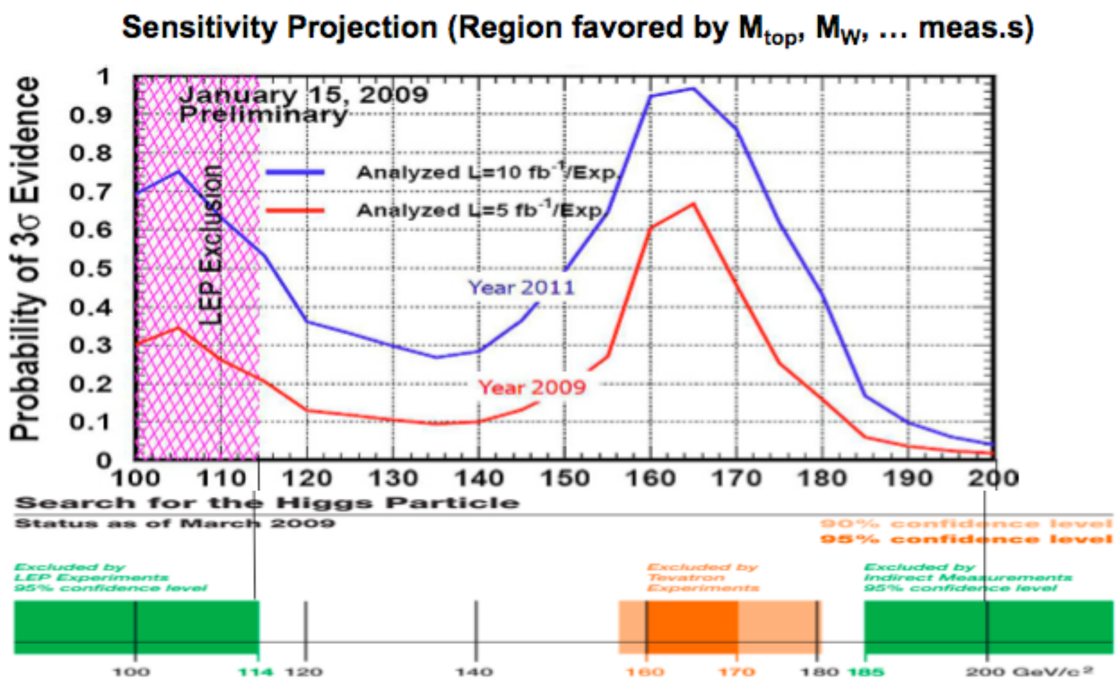
First Observation of Electroweak Single Top Quark Production

The Search for Higgs

In quantum field theory, the **Higgs mechanism** is the way by which the massless gauge bosons in a gauge theory acquire a mass by interacting with a background **Higgs field**.

The standard model of particle physics uses the Higgs mechanism to give all the elementary particles masses.

The Higgs particle has never been observed so far. Its mass is unknown

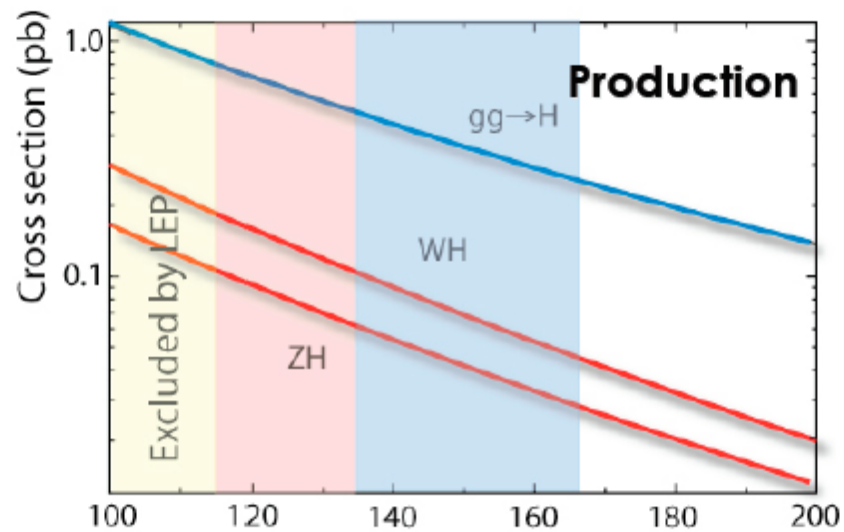


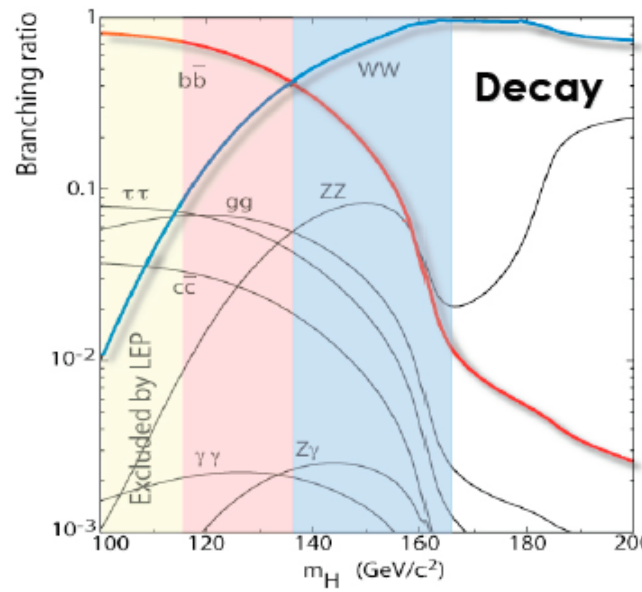
Higgs Production and Decay

SM Higgs

- Different production mechanisms
- Large backgrounds

- <u>Low Mass Higgs</u>
  - $H \rightarrow bb$, QCD bb background overwhelming
  - Use associated production to reduce background
- <u>High Mass Higgs</u>
  - $H \rightarrow WW \rightarrow l\nu l\nu$ decay available
  - Take advantage of large $gg \rightarrow H$ production cross section

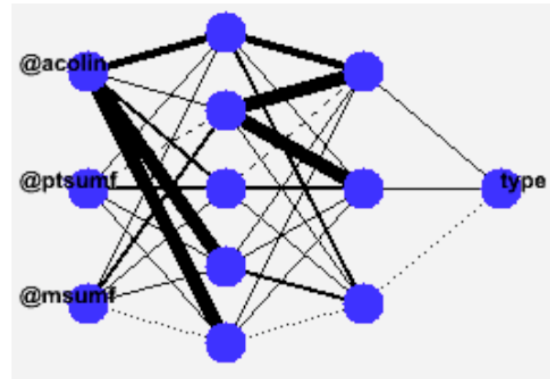




The Tools: once again MVA

In order to maximize sensitivity

- Neural Network (NN)
  - Well known technique.



- Boosted Decision Tree (BDT)
  - Relatively new.
  - BDT is fast
    → can handle more inputs.

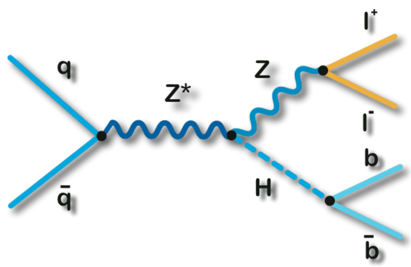
- Matrix Element (ME)
  - Event probability can be obtained by integrating ME.
  - Input is 4 momentum vector for each objects.
  - Need huge CPU power.

Major Inputs
- Dijet mass
- Pt of dijet
- Wpt, Zpt
- Sphericity
- q x η
- ΔR_{jj}, $\Delta\phi_{jj}$, $\Delta\eta_{jj}$

These three approaches are often combined by Neural Net / BDT.

SM Higgs: ZH→llbb

ZH→llbb - signature: two leptons and b jets



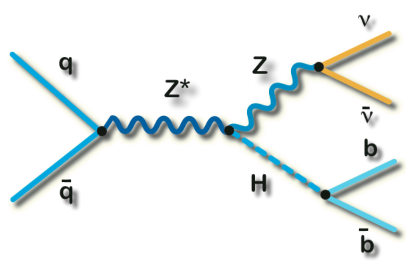
- Primary background: Z + b jets
- Key issue: Maximize lepton acceptance and b tagging efficiency
- Innovations:
  - CDF/DØ: Extensive use of loose b tagging
    - CDF:
      - Use of isolated tracks and calorimeter only electrons
      - MET used to correct jet energies, New ME analysis
    - DØ :
      - Multiple advanced discriminates, NN and BDT

Analysis	Lum (fb^{-1})	Higgs Events	Exp. Limit	Obs. Limit
CDF NN	2.4	1.8	11.8	11.6
CDF ME(120)	2.0	1.4	15.0	14.2
DØ NN,BDT	2.3	2.0	12.3	11.0

Results at m(H) = 115GeV: 95%CL Limits/SM

SM Higgs: VH→METbb

ZH→ννbb, WH→lνbb(l not detected) - signature: MET and b jets



- Primary backgrounds: QCD b jets and mistagged light quark jets
- Key issue: Building a model of the QCD background
  - Shape from 0 and 1 b tagged data samples with tag and mistag rates applied
- Innovations:

  CDF/DØ : Use of track missing p_T to define control regions and suppress backgrounds

CDF: Uses of H1 Jet Algorithm combining tracking and calorimeter information

3 jet events including W→τμ acceptance

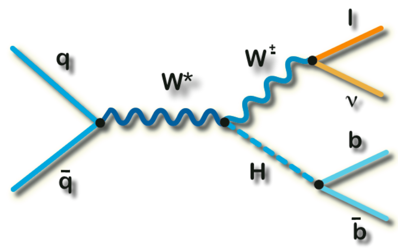
DØ also performs a dedicated W→τμ

Analysis	Lum (fb^{-1})	Higgs Events	Exp. Limit	Obs. Limit
CDF NN	2.1	7.3	6.3	7.9
DØ BDT	2.1	3.7	8.4	7.5

Results at m(H) = 115GeV: 95%CL Limits/SM

SM Higgs: $WH \rightarrow l\nu bb$

$WH \rightarrow l\nu bb$ - signature: high pT lepton, MET and b jets



- Backgrounds: W+bb, W+qq(mistagged), single top, Non W(QCD)
- Key issue: estimating W+bb background
  - Shape from MC with normalization from data control regions
- Innovations:
  - CDF: 20% acceptance from isolated tracks, ME with NN jet corrections
  - DØ : 20% acceptance from forward leptons, use 3 jet events

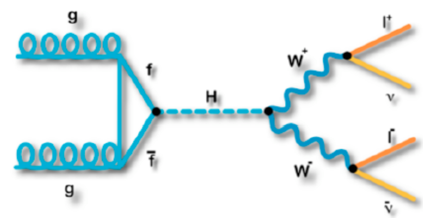
Analysis	Lum (fb^{-1})	Higgs Events	Exp. Limit	Obs. Limit
CDF NN	2.7	8.3	5.8	5.0
CDF ME+BDT	2.7	7.8	5.6	5.7
DØ NN	1.7	7.5	8.5	9.3

Results at m(H) = 115GeV: 95%CL Limits/SM

SM Higgs: H→WW

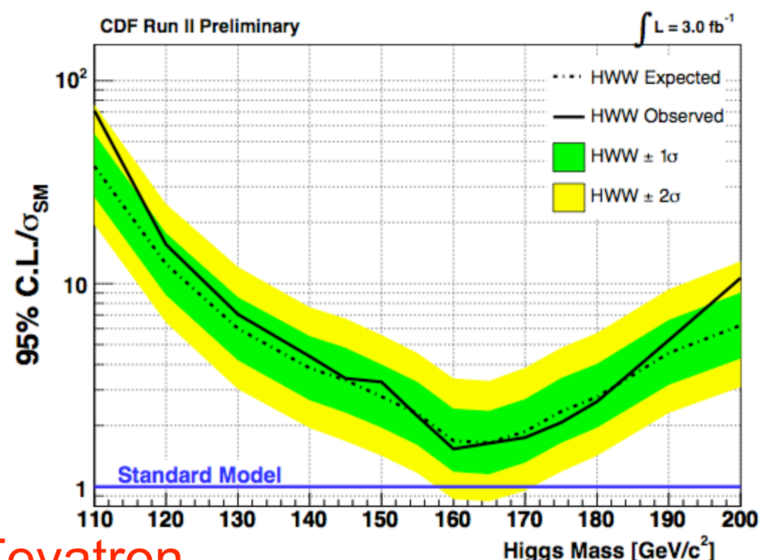
H→WW→lνlν - signature: Two high p_T leptons and MET

- Primary backgrounds: WW and top in di-lepton decay channel
- Key issue: Maximizing lepton acceptance
- Innovations:
  - CDF/DØ : Inclusion of acceptance from VH(CDF) and VBF
    - CDF : Combination of ME and NN approaches,
    - DØ : optimized NN



Analysis	Lum (fb^{-1})	Higgs Events	Exp. Limit	Obs. Limit
CDF ME+NN	3.0	17.2	1.6	1.6
DØ NN	3.0	15.6	1.9	2.0

Results at mH = 165GeV : 95%CL Limits/SM



Most sensitive Higgs search channel at the Tevatron

Other Higgs searches

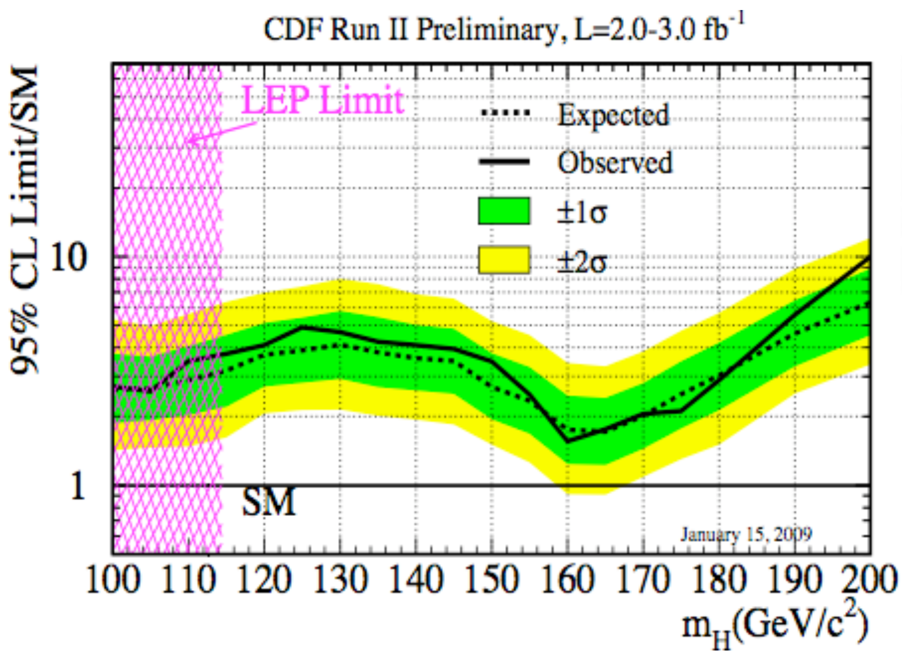
- CDF and DØ are performing searches in every viable mode
  - CDF/DØ: WH→WWW: same sign leptons
    - Adds sensitivity at high and middle masses
    - Also Fermiophobic Higgs search
  - CDF: VH→qqbb: 4 Jet mode.
  - CDF: H→ττ with 2jets
    - Simultaneous search for Higgs in VH, VBF and gg →H production modes
    - Interesting benchmark for LHC
  - DØ: H→ γγ
    - Also model independent and fermiophobic search
  - DØ: WH→τνbb, new mode
    - Dedicated search with hadronic τ decays
  - DØ: ttH, new mode

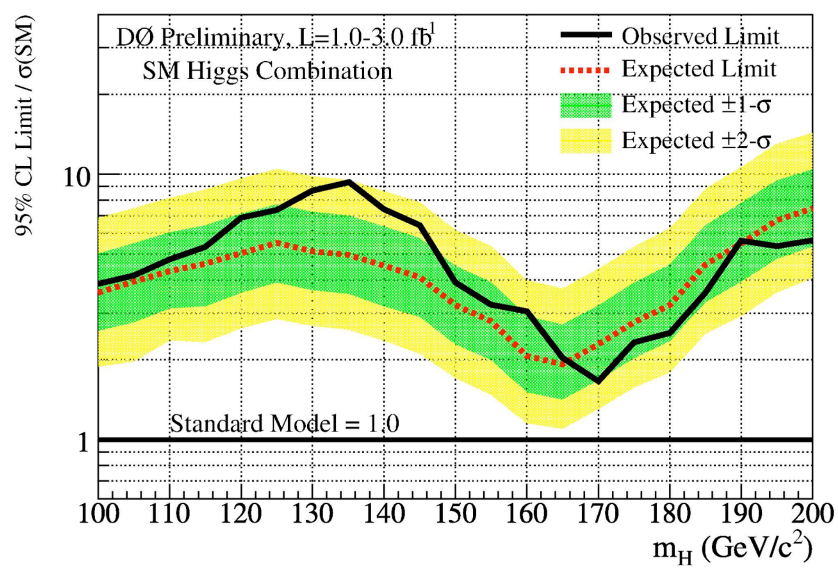
Analysis: Limits at 160 and 115GeV	Exp. Limit	obs. Limit
CDF WH→WWW	33	31
DØ WH→WWW	20	26
CDF VH→qqbb	37	37
CDF H→ττ	25	31
DØ WH→τνbb	42	35
DØ H→γγ	23	31
DØ ttH	45	64

SM Higgs Combination

Limits calculation and combination

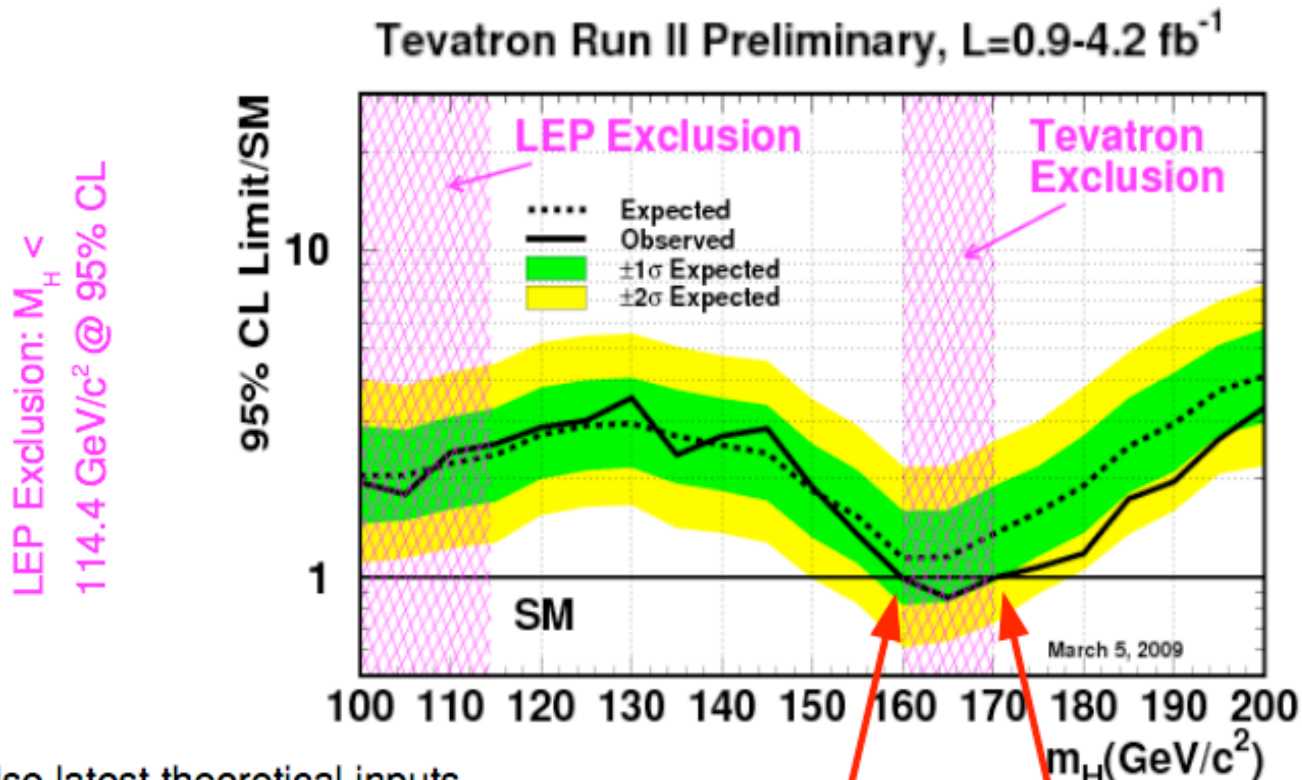
- Systematic uncertainties incorporated using pseudo-experiments (shape and rate included) (correlations taken into account between experiments)
- Backgrounds can be constrained in the fit





- Low mass combination difficult due to ~70 channels
  - Expected sensitivity of CDF/DØ combined: <3.0xSM @ 115GeV

Current Exclusion Limits

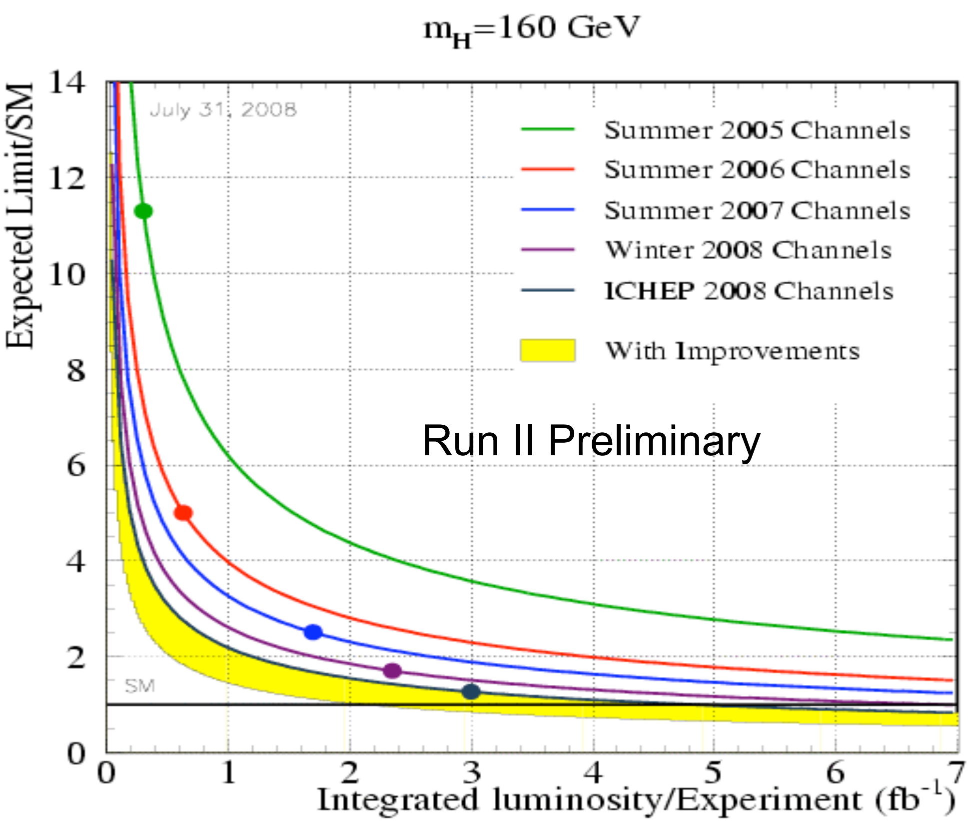


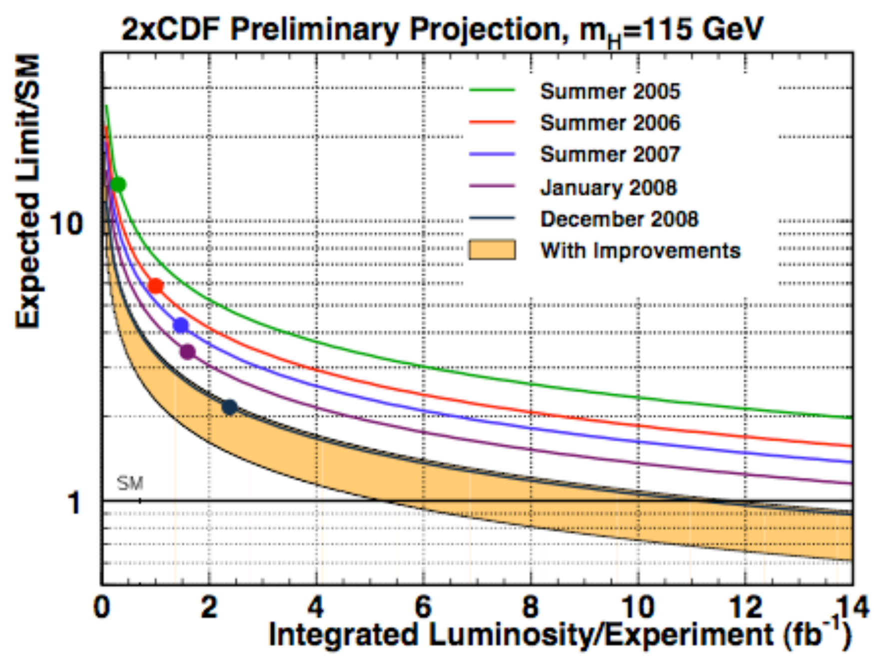
Use latest theoretical inputs including:
σ(gg→H) by C. Anastasiou, R. Boughezal & F. Petriello; and de Florian & Grazzini w/ MSTW 2008 NNLO PDF set

Bayesian	155	160	165	170	175	180	185	190	195	200
Expected	1.5	1.1	1.1	1.4	1.6	1.9	2.2	2.7	3.5	4.2
Observed	1.4	0.99	0.86	0.99	1.1	1.2	1.7	2.0	2.6	3.3
Cls	155	160	165	170	175	180	185	190	195	200
Expected	1.5	1.1	1.1	1.3	1.6	1.8	2.5	3.0	3.5	3.9
Observed	1.3	0.95	0.81	0.92	1.1	1.3	1.9	2.0	2.8	3.3

Higgs Projections at final RunII

- Goals for increased sensitivity achieved
- Expect large exclusion, or evidence, with full Tevatron dataset and further improvements.





Summary on Higgs

- Using combined CDF and D0 results -
  - SM Higgs is excluded with the mass range

    160 – 170 GeV/c^2 @ 95% CL

    http://tevnphwg.fnal.gov/results/SM_Higgs_Winter_09/
- Tevatron making great strides in high mass Higgs searches

Conclusions

- The Tavatron is still the most powerful accelerator on Earth and it is producing new physics results considered unreachable up to a few year ago.
- The analyses are becoming more and more complex and the search for the signals of interest make heavy use of new techniques, like MVA.
- Particle Physics is once more at the forefront concerning the analysis and interpretation of very large data sets

Backup

The Thrill of Discovery: A Brief History of CDF

- 1985: First collisions with partial detector
- 1987: Core detector in place. Jet Physics
- 1988-89: "Run 0" 4x the expected data, seen lots of W/Z's
- 1992-1995 : "Run I" -added silicon detector. Top quark discovered!

- 2001: Run II era begins with essentially a new detector, higher collisions energy and more data.
- 2004: First Run II physics papers published
- 2007: trying to catch the Higgs

12 countries, 59 institutions
706 physicists

Drawbacks on the use of multivariate techniques

Adding too many weakly discriminating variables to a multivariate analysis will actually degrade rather than enhance the ability of distinguishing between signal and background

Any added variable may or may not add discriminating power between signal and background, but will always add statistical noise.

Example: a signal sample is generated using a 5-dim Gaussian probability function and a sample of background events is also generated using a 5-dim gaussian PDF, identical in every way to the signal except that the mean in one dimension is shifted by 1-sigma from the signal mean.

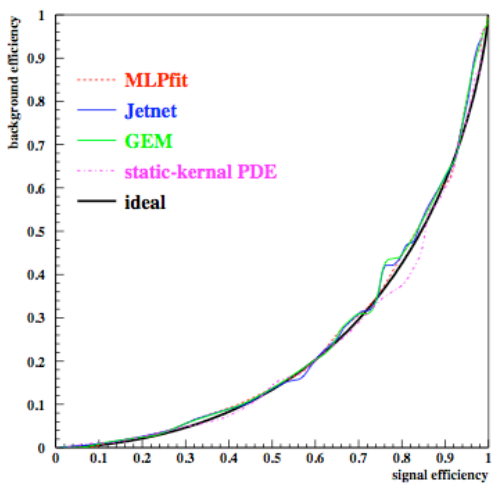


Fig. 1: Background efficiency versus signal efficiency as obtained by four different multivariate techniques under the hypothesis that the signal and background are both unit-width one-dimensional Gaussians separated by one unit.

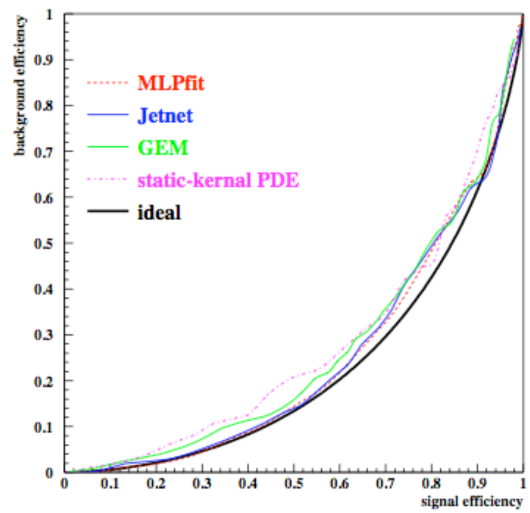


Fig. 2: The same as Figure 1, except that four extra, non-discrimating variables have been added to the analysis. The discrimination power of all the multivariate techniques is significantly degraded by the statistical noise added by these four variables.

How to overcome this?

Various methods to reduce the number of variables:

Quick sort through the list of variables to find the ones best discriminating between signal and background
For each variable the user performs a univariate analysis determining $S/\sqrt{S+B}$ and chooses the one variable that appears to afford the best discrimination and better describe the data. The variable forms the nucleus of the accepted set of variables. Now an iterative process begins with all the other variables and $S/\sqrt{S+B}$ is re-determined for each combination: the variable is added to the set if the discriminating power is better than the previous step.

The number of variable finally found is generally dependent of the training sample size. One way to optimize this is to add dummy variables that allow to test the null discrimination hypothesis..

Genetic Algorithms..